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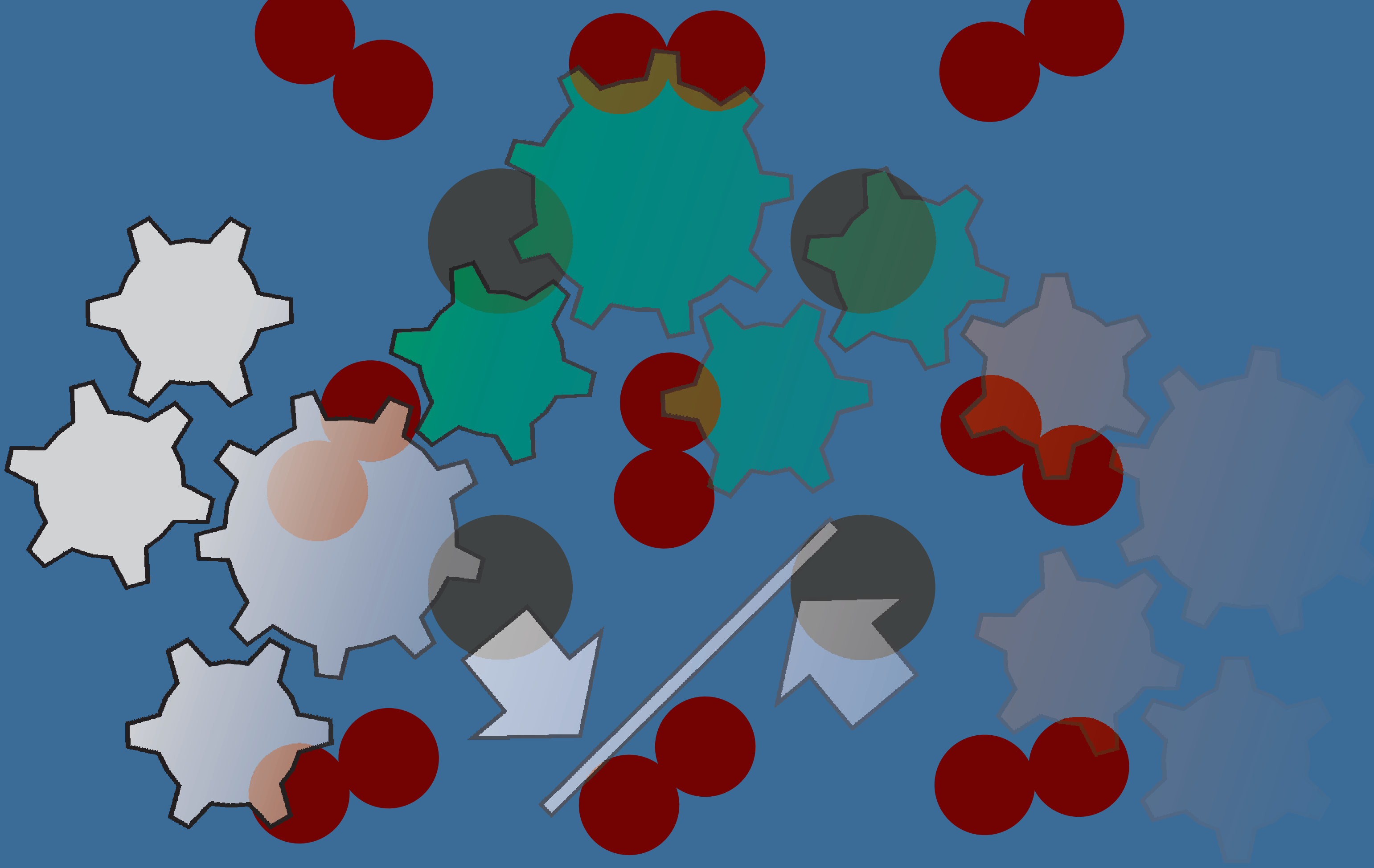

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USE OF ADDITIVE MANUFACTURING IN VETERINARY MAXILLOFACIAL PROSTHETICS

Jana Klímová
Department of Biomedical Engineering and measurement, Faculty of Mechanical Engineering, Letná 1/9, 042 00, Košice, Slovakia, EU, jana.klimova@tuke.sk
Alena Findrik Balogová
Department of Biomedical Engineering and measurement, Faculty of Mechanical Engineering, Letná 1/9, 042 00, Košice, Slovakia, EU, alena.findrik.balogova@tuke.sk, (corresponding author)
Marianna Trebuňová
Department of Biomedical Engineering and measurement, Faculty of Mechanical Engineering, Letná 1/9, 042 00, Košice, Slovakia, EU, marianna.trebunova@tuke.sk
Radovan Hudák
Department of Biomedical Engineering and measurement, Faculty of Mechanical Engineering, Letná 1/9, 042 00, Košice, Slovakia, EU, radovan.hudak@tuke.sk
Jozef Živčák
Department of Biomedical Engineering and measurement, Faculty of Mechanical Engineering, Letná 1/9, 042 00, Košice, Slovakia, EU, jozef.zivcak@tuke.sk

Keywords: veterinary medicine, orthodontics, 3D printing, maxillofacial, prosthetics
Abstract: The article is focused on orthodontic disorders and the use of additive production in solving problems in the maxillofacial area. Important information in veterinary orthodontics is the knowledge of the most common orthodontic disorders occurring in animals of various species and the consequences of not resolving these disorders. Dental health is no less important for both domestic and farm animals. With new approaches such as additive production, it is possible to achieve individualized aids that can be applied to any animal. The aim of the article is to draw attention to additive production and to point out its potential in the field of veterinary orthodontics. Examples of the use of additive production in this area can be found at the end of the work.

1 Introduction

Additive manufacturing is currently gaining prominence in many areas. Thanks to various successful applications, it has also found application in veterinary medicine and is gradually beginning to be used to solve various orthodontic disorders in animals. The potential of 3D printing in veterinary orthodontics lies mainly in its flexibility, adaptability and ability to print even small and detailed objects, which is very desirable and appreciated in the production of orthodontic appliances. Orthodontics in the veterinary field deals with the direction of the growth of animal teeth. In general, it could be said that animal orthodontics deals with a greater extent with cases where the treatment of teeth is necessary for the animal, especially from a health point of view, as opposed to the humane one, which is also interested in cosmetic treatment. The primary goal of animal orthodontics is to provide the animal with relief from pain caused by improper dental growth, bite disorders — i.e., small occlusion, improper tooth count, persistent deciduous teeth, blocked teeth, FRLs- Feline odontoclastic resorptive lesions, or diastema. It is estimated that of the dog population, only 7% are completely free of any dental problems. The teeth, together with the entire oral cavity, are the gateway to the body, and thus the health of this part is extremely important for the overall health of the individual. The target group is various animals, including dogs, cats and, for example, rabbits and other small animals.

The relative position of the upper and lower rows of teeth is called occlusion. It is basically a clash of upper and lower incisors with the mouth closed. Normal bite in a dog occurs when the six upper incisors are placed just in front of the six lower incisors (*Figure 1* A). The lower ocular tooth fits between the upper ocular tooth and the incisor so that there is no friction between them and they do not interfere (*Figure 1* B). The molar teeth fit together in the shape of a triangle (*Figure 1* C). Occlusion is largely genetically determined, but it is also affected by the animal's nutrition, the environment in which it lives and also mechanical damage. Sometimes, however, occlusion acquires various abnormalities, resulting in a wide range of dental disorders. Some abnormalities are also genetically determined, such as malocclusion, specifically pre-bite and under-bite, but many of them only occur during the life of the animal. In dogs, the frequent trigger is too strong and often stretched, for example, with a rope or towel, which causes the teeth to move to an unusual position. Complicated childbirth and the injuries that can occur also affect the condition of the teeth, and even then, the first signs of abnormalities may appear. Malocclusion is one of the most common diseases in the field of animal orthodontics. It is a bite disorder that is caused by the incorrect position of the teeth and includes pre-bites or under-bites. A relatively common phenomenon is non-decayed deciduous teeth, missing teeth, or, conversely, an excessive number of teeth in the oral cavity [1].

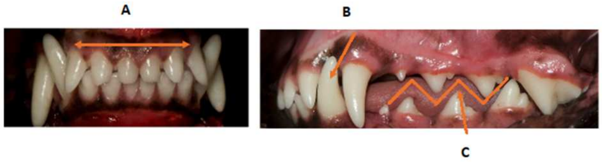

Figure 1 Normal bite in a dog

Because the oral cavity is never sterile, orthodontic procedures allow various bacteria to enter the air from the patient's mouth and wounds, so it is ideal to have a separate room reserved for such procedures.

During the treatment of the oral cavity and teeth, the patient is under general anaesthesia with endotracheal intubation. This prevents bacteria and other pollutants from being inhaled back from the air and also suffocates the animal. The pharyngeal wrap is also recommended but must be removed before extubation [2].

2 Basic orthodontic appliances

2.1 Coronal tooth amputation

It is accessed in the case of FRLs. In larger cases, it is no longer possible to save the tooth after the onset of the disease, and therefore amputation of the affected tooth is necessary to at least alleviate the pain. The entire extraction process is monitored at X-ray intervals at regular postoperative intervals to ensure that the tooth root is resorbed and that healing occurs without complications. The aim of this technique is to ensure that the tooth pulp remains undamaged and that the other teeth develop normally and contribute to the overall strength of the jaw [2][3].

2.2 Orthopaedic wire

Interdental or interfragmentary techniques, or combinations thereof, are used to repair certain jaw injuries, including fractures. With the help of wire sutures, tension wires, or intraosseous (intraosseous) screws, the primary fixation of large jaw fragments is ensured. Many veterinarians use a stabilizing technique of cerclage wire applied to the teeth of a dog. For cats, nylon suture is used instead of wire. Jaw damage is usually removed in 4 to 6 weeks. An X-ray is required to confirm the remedy, and then the wire is removed [2].

2.3 Tooth extraction

This technique is usually indicated for small animals. Extraction of the whole tooth is a relatively large intervention in the oral cavity of the animal, and an alternative may be endodontic therapy or reconstruction of the crown. The advantage of extracting the whole tooth is the elimination of any pathological changes on the left residue. The most common causes of this procedure are malocclusion, persistent deciduous teeth, or the excessive number of teeth **Chyba! Nenašiel sa žiaden zdroj odkazov.Chyba! Nenašiel sa žiaden zdroj odkazov.**.

2.4 Removable orthodontic appliance/aid

An underbite is a relatively common orthodontic problem in dogs. This malocclusion can be caused by a dental abnormality, a skull skeletal abnormality, or a combination of both. The tips of the eye teeth of the lower jaw cause unpleasant pain in the upper climate. If the problem is not solved, holes may even form in the climate, resulting in infections or ulcerations. A removable orthodontic appliance can be very helpful in this case, and correction of malocclusion can occur after only three to four weeks. However, if there are no signs of improvement after three weeks, another method must be used. The advantage is, among other things, that during the use of the device, the owner's relationship with the dog improves because the dog takes the device as a game. However, this technique is not suitable for all cases, especially not for puppies with deciduous teeth. This is because deciduous teeth are very brittle and prone to breakage. It is effective for adult dogs with long-lasting teeth, which, however, have no other orthodontic problems [2][4].

3 Materials and aids used in veterinary orthodontics

As the demand for veterinary dentists has been increasing more and more recently, the requirements for the quality of their work have also increased. The basic procedures practised by dentists include dental hygiene, surgical extraction of multi-root teeth, orthodontics and the like. For such operations, it is necessary to have adequate technical equipment, including various hand tools, dental ultrasonic scaler cleaners (scanners), polishers, or more professional high-performance dental units and X-ray systems [2].

3.1 Dental plates

There are many types and sizes of dental plates designed for use in dogs and cats. In the case of other animals, due to the different widths and lengths of the patient's mouth, the plates are made to measure individually [5].

3.2 Imprint

Toothache is an essential part of many dental procedures. It allows the doctor to determine the shape and condition of the oral cavity and to design a possible denture [5].

3.3 Tooth model

The tooth model should be made as soon as possible after the casting has been made. Thanks to the model, it is possible to evaluate oral structures, orthodontic bites, design a plan for treatment, or create orthodontic aids **Chyba! Nenašiel sa žiaden zdroj odkazov.**.

3.4 Fixed apparatus

It is used to apply forces to the teeth in order to achieve orthodontic movements. The fixed apparatus is not intended for all animals. In the beginning, it is necessary to consider the temperament of the animal, whether it will tolerate this orthodontic appliance, whether it has no signs of aggressive chewing of food, which could be a major complication, or whether extraction is simply not more appropriate [4].

3.5 Rings

In orthodontics, they are used to direct the tooth in the right direction of growth but also to fasten other acrylic and metal orthodontic appliances [5].

3.6 Brackets

Brackets are used to correct incorrectly turned teeth. On the prefabricated model, the lines according to which the breeches are placed are marked with a pencil [5].

3.7 Orthodontic wires

Annotations 188 wires are most commonly used in veterinary orthodontics, meaning that the wire consists of 18% chromium, 8% nickel, and the remainder is iron. Elgiloy wire, which also contains cobalt and molybdenum, is also relatively common [5].

4 Use of 3D printing in veterinary maxillofacial prosthetics

Although 3D technology has been used in human medicine since 1990, the first use in veterinary medicine did not appear until the early 21st century. The first registered cases concerned the treatment of complications in dogs with the incorrect forearm and thigh growth. The solutions consisted of the use of SLA technology of 3D printing for the production of preoperative models, which ultimately shortened the total time of the operation itself and reduced the risk of various complications. Since then, additive production has slowly spread to all branches of veterinary medicine, including orthodontics. However, it still does not use the full potential of 3D printing technology in dentistry, and so far, there are very few specific clinical studies that would offer additive manufacturing as a solution to orthodontic disorders. In a larger proportion, maxillofacial prosthetic devices are applied after injuries or cancer [6][7][8].

4.1 3D printed implant for labrador

A 15-month-old labrador lost a tooth after an injury while playing. This caused him complications in eating. The dog stopped eating and began to be apathetic. Since it was a loss of permanent teeth, it was necessary to look for a solution, because there was a threat that the dog would become malnourished. The first step was to create a casting of the upper jaw, and then the 3D design specialists created a model of the tooth, which will be made of metal, using chromium and cobalt (Figure 2 A). A scan of the same tooth from the other side of the mouth helped them to ensure complete adjustment of the implant. During the manufacture of the implant, it was necessary to pay attention to a thorough and accurate measurement so that the tooth fits perfectly, as it was a very small space (Figure 2 B). As a result, the extruded tooth was even harder than the original, but even so, in such cases, it is no longer recommended to let the dog bite hard objects, such as bones, to prevent possible implant fractures. The tooth took hold and the dog began to eat again after a short recovery (Figure 2 C) [9].

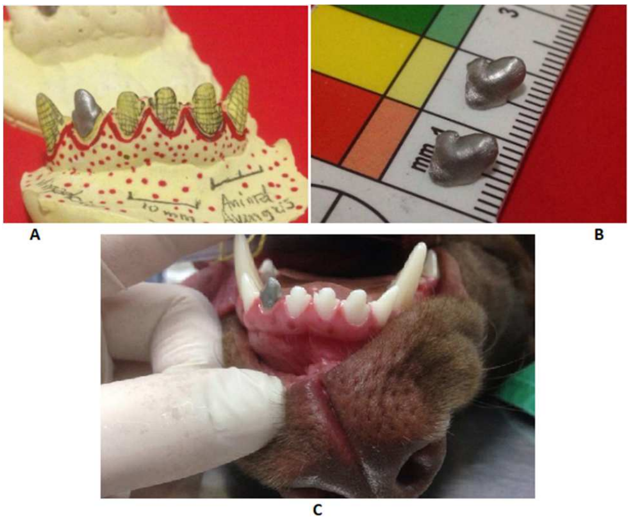

Figure 2 Jaw casting (A), thorough implant measurement (B), finished applied implant (C)

4.2 The helmet as an orthodontic aid for cockatiels

As some rhino prostheses made for birds, which only serve to correct the deformed beak, tend to loosen, in 2019, French veterinarian Minh Huynh managed to produce an alternative. It is a 3D printed helmet for a cockatiel, which is to serve as an orthodontic aid for beak correction (Figure 3). However, according to the author, its effects are still being investigated, and there is currently no more public information about it [8].

Figure 3 3D printed helmet for beak correction for cockatiel

4.3 Face mask for a turtle

A 30-year-old turtle suffered an injury under unknown circumstances, which caused a small wound to the right nostril. The wound began to fester, and there was a risk of the infection spreading. The veterinarians managed to clean the pus but was left with a deep wound in which food, clay and moss were constantly jammed. A year of intensive wound cleaning led veterinarians to look for a more permanent solution, which came in the form of a 3D printed mask that would prevent dirt from entering the wound. However, they faced a great challenge because the mask had to have the exact dimensions and shape so that the head of the turtle could fit into it and also that the mask did not restrict it in activities such as breathing or eating. The final mask was preceded by several test trials, which served as teaching aids. Based on detailed images of the turtle's face captured by a micro-scanner, technicians designed a mask that was large enough to fit a head but small enough to fit into armour and prevent the turtle from eating, seeing, and breathing. The mask was attached to the turtle with a screw that passes directly through the wound to the mouth, where it is fixed with composite resin. Figure 4 is a photograph of a turtle already with a face mask applied [10][11].

Figure 4 Turtle with the mask applied

4.4 Replica sledge for sea turtle

In June 2015, a 45-kilogram sea turtle got too close to a motorboat, whose propeller hit it several times. This caused extensive injuries to her upper and lower sledges. Injuries severely limited her food intake and ability to swim. Volunteers from the Turkish university PAU began looking for a solution to help it. In cooperation with the local 3D printing centre, they managed to make an exact replica of the missing part of the jaw. Based on a CT image of the turtle, they created a 3D model of the implant of the missing part of the jaw and its adjacent part using the software. Despite many experiences with human implants, this project was a relatively big challenge for the authors because the turtle has completely different anatomy and tissues than humans. Prior to finalization with the press itself, many motion analyzes were performed, as the strength of the turtle's jaws is very large. The implant was finally extruded from medical titanium, and several orthopaedic screws were used to attach it to the turtle. **Chyba! Nenašiel sa žiaden zdroj odkazov.** is a photograph of a turtle with an applied implant after surgery and 3D models of the upper and lower jaw implant **Chyba! Nenašiel sa žiaden zdroj odkazov.**.

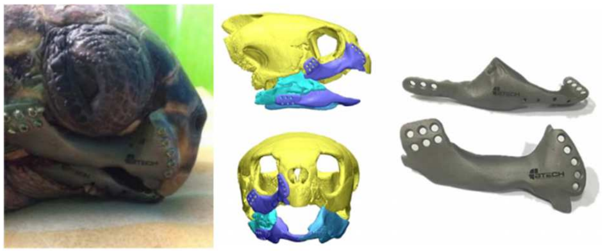

Figure 5 Turtle after implant application (left) and 3D models of the implant (right)

4.5 Maxillofacial mask for dog

In November 2017, an international group of surgeons from Germany, Canada and the United Kingdom teamed up to help the 7-year-old Bernese Mountain Dog with cancer through additive production. He had an operation during which he had to surgically remove a tumour in the left part of his upper jaw, which would cause him to lose a substantial amount of hard tissue. Due to the size and complexity of the affected area, surgeons opted for a customized 3D extruded titanium implant to replace the bone structure.

Whereas once individual printed devices were used only for a few patients with complicated cases, today, thanks to technological advances from individual printed devices, special medical CAD tools are becoming part of standard veterinary and human practice. Using DICOM (digital tool for imaging and communication in medicine), a 3D model of the affected part of the dog's head was generated on the basis of CT / MRI images. Using the model, an implant design was created, which was then repeatedly compared and measured according to 3D scans and head models before printing so that it fits as well as possible, see Figure 6. As a result, the placement of the implant was much simpler, more predictable and faster, which made it possible to shorten the time during which the dog had to be under general anaesthesia. The process of designing and printing the device itself lasted a total of two weeks, which was an advantage because the tumour was constantly growing, and if the manufacturing process stretched for a long time, the extruded implant would no longer have to fit. During an operation led by Canadian veterinary surgeon Julius Liptak, his entire tumour was removed, including adjacent infested areas measuring 45 millimetres x 50 millimetres and 30 millimetres thick. The photograph from the course of the operation is shown in Figure 7. They then applied an implant in place, which they fastened with surgical screws. A prepared skin flap was used to cover the affected area and the implant. This ensured that the structure of the nose did not have to be modified due to the missing tissue, thanks to which the dog did not feel any extraordinary physiological changes after the operation. The day after the operation, the dog could go back to home care, and after a few days, he was able to breathe normally and eat himself. X-rays of the implant applied to the dog's jaw are shown in Figure 8. An individual 3D printed maxillofacial mask will provide him with a long and full life without restrictions, which, however, would not be possible without 3D printing technology, as the tumour-affected part of the face was very large [13].

Figure 6 The 3D model of the implant itself (left) and preparation for surgery using a 3D model of the head (right)

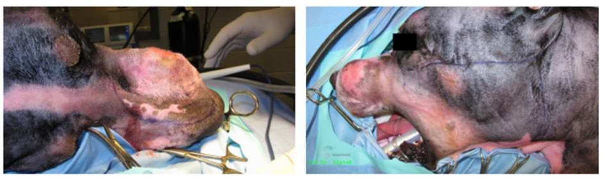

Figure 7 The course of the operation

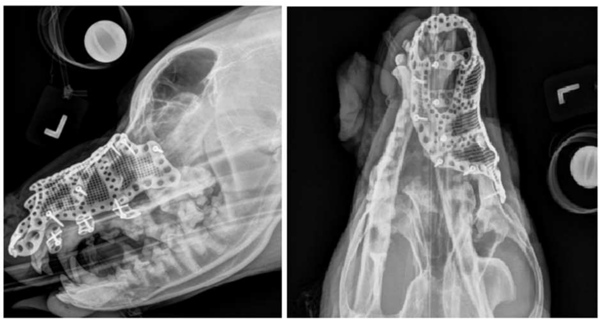

Figure 8 X-ray after surgery: side (left) and bottom view (right)

5 Conclusions

The article deals with orthodontic disorders in various animals, aids that are used to solve these disorders and the use of 3D printing in this area. The aim was to summarize the knowledge of the issue and process it into an overview theoretical work aimed at raising the potential of additive production in veterinary orthodontics.

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ANALYSIS OF THE SELECTED SIMULATION SOFTWARE PACKAGES: A STUDY

Kateryna Kovbasiuk
Technical University of Košice, Faculty of Manufacturing Technologies with a seat in Prešov, Department of Industrial Engineering and Informatics, Bayerova 1, 080 01 Prešov, Slovak Republic, EU,
kateryna.kovbasiuk@tuke.sk (corresponding author)
Kamil Židek
Technical University of Košice, Faculty of Manufacturing Technologies with a seat in Prešov, Department of Industrial Engineering and Informatics, Bayerova 1, 080 01 Prešov, Slovak Republic, EU,
kamil.zidek@tuke.sk
Michal Balog
Technical University of Košice, Faculty of Manufacturing Technologies with a seat in Prešov, Department of Industrial Engineering and Informatics, Bayerova 1, 080 01 Prešov, Slovak Republic, EU,
michal.balog@tuke.sk
Liudmyla Dobrovolska
Kharkiv Polytechnic Institute, Institute of Education and Science in Mechanical Engineering and Transport, Department of Technology of Mechanical Engineering and Metal-Cutting Machine Tools, Frunze 21,
610 02 Kharkov, Ukraine, liudmyla.dobrovolska@khpi.edu.ua

Keywords: Industry 4.0, simulation, discrete-event simulation, simulation software package
Abstract: The simulation software market is becoming more complex and universal. Computer simulations are thus more accessible and are becoming a modern tool that has a wide application in industry. Their potential and benefits can be used in small and large projects. A simulation model can take into account inventory, assembly, production and human resources, leading to decisions that can maintain or improve efficiency at the lowest possible cost. The data obtained through the simulation allow to test different combinations and scenarios in the virtual world. The benefits of manufacturing simulation include reducing investment risk, minimizing waste, improving efficiency, reducing energy consumption and even increasing worker health. The question arises as to which of the possible simulation packages is the most suitable for a given company, so that the investments made are the best possible. In the first part of the paper the theoretical basis of simulation in Industry 4.0 is presented, including the description of the possible simulation modelling tools. The second part of the paper offers comparative and descriptive analysis of six selected discrete-event simulation software packages – AnyLogic, Arena, FlexSim, SIMUL8, Tecnomatix Plant Simulation and WITNESS. The given simulation tools are compared based on their main characteristics, simulation features, application areas and popularity among the companies which use simulation software packages.

1 Introduction

The Fourth Industrial Revolution (Industry 4.0) assumes a new approach to production based on the massive introduction of information technology in industry, large-scale automation of business processes and the development of artificial intelligence. The advantages of the Industry 4.0 are clear: increased productivity, greater worker safety by reducing jobs in hazardous working conditions, increased competitiveness, ground-breaking products, and much more. Achieving Cyber-Physical Systems and Smart Factories is the goal of the Fourth Industrial Revolution.

The desire to implement its concept leads to the need to use the capabilities of modern computer simulation, since it is an effective means of researching new processes and testing new products, devices and technologies. Due to the complexity and interconnectedness of scientific and production tasks formulated within the framework of the Industry 4.0 concept, it becomes necessary to apply a variety of types of simulation, regardless of whether it is customary to call them simulation modelling or not.

1.1 Industry 4.0

The Fourth Industrial Revolution (Industry 4.0) is a transition to fully automated digital production controlled by intelligent systems in real time in constant interaction with the external environment, going beyond the boundaries of one enterprise, with the prospect of uniting into a global industrial network of things and services. The purpose of Industry 4.0 is to build a highly flexible production model of personalized and digital products and services, with real-time interactions between people, products and devices during the production process [1]. In a narrow sense, Industry 4.0 is the name of one of 10 projects of the Germany's Hi-Tech strategy 2020, describing the concept of Smart Manufacturing based on the global industrial network of the Internet of Things and Services [2].

Industry 4.0 consists of a wide range of fundamental concepts such as Smart Factory, cyber-physical systems, decentralization, individualization of distribution and procurement, adaptation to human needs etc. [3]. There are three main elements ensuring the effectiveness of the Industry 4.0 performance [4]:

- Horizontal integration across the entire value creation network (it includes every link, which is in the value chain as well as the relationships that are formed, developing and maintaining value-creating and value-adding networks) [5][6][7][8][9].
- Manufacturing systems, vertical and network integration (it is the process of connecting all levels of a manufacturing enterprise – from the technological site and workshop to the level of administrative management).
- End-to-end engineering (analysing data collected throughout the manufacturing process in a systematic manner, allowing for quick decisions and product or service follow-up with an emphasis on quality and customer satisfaction).

The main difficulties in implementing Industry 4.0 are associated with the following factors:

- Price. Although it is potentially beneficial to upgrade systems to Industry 4.0 standards, a significant initial investment is needed.
- Technical difficulties. With more technology and less human oversight, there is a risk of technical problems that can be costly.
- Layoff. With any technology upgrade, there is a risk of job loss, and Industry 4.0 is no exception, however, there are also forecasts that industrialization will create more jobs than it will eliminate.
- Cybersecurity issues. When the entire enterprise is connected to the Internet, cyber security issues may arise.

However, there also exists a number of considerable benefits such as the following:

- New opportunities. With the help of analytics and data, companies can find ways to expand their business and enter new markets.
- Efficiency. Using robotization and automation, products can be produced faster and more efficiently, especially when smart technologies are involved.
- Saving money. By adopting Industry 4.0 principles and technologies the risk of costly mistakes can be reduced.
- Improvement of the customer experience. The analysis of customer needs and customization lead to fast reactions on customer demands and increased competitiveness.
- Increased income. Despite the high initial investment, Industry 4.0 can generate much more revenue for companies. This can be attributed to higher efficiency, fewer defects, new opportunities, and better customer experience.

Industry 4.0 is based on digital and physical technologies with the former considered to be closely connected to modern communication and information technologies and the latter to manufacturing. Those technologies are the following [10]:

- Additive manufacturing
- Artificial intelligence
- Augmented reality
- Autonomous robots
- Big data and analytics
- Blockchain
- Cloud
- Cobotic systems
- Cybersecurity
- Unnamed aerial vehicle
- Global Positioning Systems
- Internet of Things
- Mobile Technology
- Nanotechnology
- RFID
- Sensors and actuators
- Simulation

1.2 Simulation in Industry 4.0

The main purpose of simulation tools is to enable enterprise management to use the results of calculations when making decisions. Such tools help to check, confirm and ensure the declared properties of the product, produce the most complex and high-quality goods according to the highest standards, achieve economic efficiency of production, and minimize the design time and the number of full-scale tests. The importance of simulation tools in the infrastructure of modern production management is growing from year to year as the requirements for product quality and the complexity of technical objects increase.

Simulation is also a basic element of some Industry 4.0 technologies and concepts, for example, its application in hybrid modelling, data analytics, simulation-based training/product design, designing connectivity. Thus, simulation has an important role in fulfilling the Industry 4.0 vision [11].

The prerequisite for the implementation of the simulation is the creation of a model in the simulation program. Together modelling and simulation represent a problem-solving tool for various spheres such as engineering design, education, prototyping and concept evaluation, forecasting, education and training, risk/safety assessment, performance evaluation, sensitivity analysis, evaluation of decisions or action alternatives etc. [12] One of the most prominent application domains for simulation is manufacturing: there its full potential can be fulfilled and, moreover, some issues in industry can only be solved with the help of simulation product development variations. Apart from obvious advantages, simulation

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offers manufacturing a great number of benefits such as providing efficient trainings for new operators or for refreshing skills of experienced ones, reducing risks, start-up times, commissioning time and cost [13].

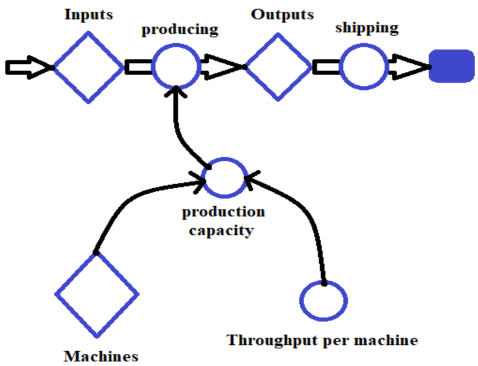
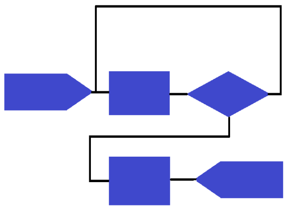
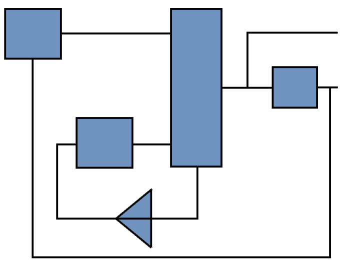
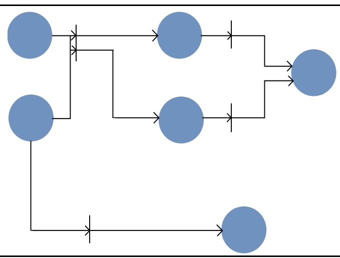
1.3 Simulation modelling tools

Today there is a great number of analytical software products focused on simulation on the information technology market. The range and variety of such software continues to grow. As the dominant basic concepts in modern simulation modelling are used [14]:

- discrete-event simulation systems (description-based systems for process description);
- systems based on network paradigms (are used in structuring causal relationships and modelling systems with parallel processes, serving for stratification and algorithmisation dynamics of discrete and discrete-continuous systems);
- systems based on process models and organizational structures;
- systems focused on continuous modelling;
- dynamic systems;
- other.

Table 1 shows environments oriented towards different approaches in simulation modelling, which shows that the market is very uneven [14].

Table 1 Environments oriented towards different approaches in simulation modelling

Systems focused on continuous modelling		Vensim, iThink, Powersim, AnyLogic
Discrete-event simulation systems		AnyLogic, Arena, SIMUL8, FlexSim, Tecnomatix Plant Simulation, WITNESS
Dynamic systems		MATLAB
Systems based on network paradigms		ARIS

In this paper the emphasis is going to be on the discrete-event simulation – the most commonly used simulation system. The majority of companies prefer commercial simulation software products to general-purpose programming language [13].

2 Methodology

The fulfilment of the tasks set in the work is carried out on the basis of the application of general scientific research methods within the framework of comparative analysis, as well as through the graphic interpretation of information. The study consists of the descriptive research of the six selected discrete-event simulation software packages that can be implemented in Industry 4.0 – AnyLogic, Arena, SIMUL8, FlexSim, Tecnomatix Plant Simulation, and WITNESS (Table 2). Those software simulation modelling tools are chosen for further comparative analysis of their main features and application areas. The literature review of those software's applications and case studies is conducted using 35 articles taken from academic journals published from 2015 to 2021 and one article published in 2010.

2.1 Application of the selected simulation software packages based on literature review

Tecnomatix Plant Simulation was used to analyse the bottleneck process and scheme comparison of two logistics solutions for an automatic plant [15] and for designing and simulation of the mining rail transport to get an objective view of their systems, though the program is mainly used for the manufacturing processes [16]. This software was considered the most appropriate tool for the computer simulation of automated guided vehicles systems [17] and one of the best solved software in the area of production solutions [18]. It was also noted that by using this simulation software, enterprises cannot only save costs but with the help of monitoring system they have undesirable effects and failures reported [19] and have considerable improvements in the production process efficiency [20].

Using **FlexSim** simulation software it is possible to determine the most cost-efficient way of production process reorganization and analyse individual results and subsequent optimization [21]. Moreover, the cyber learning factory for operations management-oriented smart factory education and training was created in FlexSim simulation environment and can be used to train information systems architects of IT companies and operations managers of manufacturing companies [22]. FlexSim can also be a helping simulation tool in decision making systems [23] and optimization of manufacturing industry [24]. It allows to experiment with other manufacturing processes without interrupting the running process [25] and is easy to use providing a dedicated environment for manufacturing simulation [26].

Models developed in **AnyLogic** simulation environment are used as a helping tool for analysts in decision making and allow to estimate the efficiency of vehicle schedules [27]. AnyLogic simulation software is also used for pedestrian flow simulation in crowded areas [28], for analysing and realizing the security system, including information security and perimeter [29], for comparison of different approaches to highway management [30] and for the integration of enterprise inventory resource [31]. The system also allows to use the built-in genetic algorithm to optimize the model's primary parameters [32].

Arena is a discrete-event simulation software originally developed by Systems Modelling Corporation and later acquired by Rockwell Automation. Mostly the discrete event methods are used but there are also tools available to cover areas in agent-based and flow modelling. This simulation tool uses flowchart modelling methodology and models can be enhanced with 3D animation [33]. Arena simulation software provided "as-is" model for adoption of Hold Baggage Security Screening (HBSS) system model at Kuwait International Airport in order to improve a system performance [34]. This simulation tool was also used to evaluate the performance measures of the queueing system [35], determine the reason of queueing occurring at berth allocation [36] and to design security-check systems for screening aviation passengers [37]. Arena is commonly used for conducting experiments based on abstract model to estimate the chances of the implementation and applicability of the proposed systems [38] and for improvement of the service level by exploring the staffing schemes [39].

SIMUL8 is a software package used for discrete event simulation but is commonly used for a process simulation, not a production one. Even though it may not be the most suitable software for the manufacturing processes analysis but it is easy to use and the results of the simulation performed in SIMUL8 environment can be simply interpreted [40]. It is a great tool to explore possible "what-if" scenarios, create a visual model of distribution and manufacturing purposes [41]. SIMUL8 is also used for rail system design, train formation operational processes and metro timetable evaluation, and railway utilization analysis since it provides a proper flexibility to perform simulation trials of various scenarios [42], [43]. The given software was compared with the four other simulation software packages – OpenTrack, Xpress MP, Arena, RailSys – to choose the most suitable one for railway simulation modelling to prove the feasibility of the proposed baggage transfer service. As a result, SIMUL8 was suggested as the best computer-based simulation software due to its easiness of use and user-friendly interface [44].

WITNESS simulation software uses simplified models that can recreate basic business processes and this system is capable of reproducing various situations. It can determine crucial processes and validate real output using production data [45]. WITNESS was also used to analyse issues connected with assembly line and resulted in operator's productivity increase and assembly line efficiency improvement [46]. It represented a helping simulation tool when it came to optimal utilization of resources, solution for material handling in warehouses and smooth customer-oriented material flow [47]. Together with industrial engineering methods this simulation software package can be used for significant balance improvements of the production line [48]. WITNESS is a general purpose simulation software thus it was suitable for traffic and single-lane roundabouts simulation [49]. Considering its advantages and application industries, WITNESS served as a basis for a simulation method of teaching of logistics, giving students the opportunities and simulation environment to apply their theoretical knowledge and create production models [50].

Table 2 Environments oriented towards different approaches in simulation modelling

Software	Developer	Package modules	Areas of use	Deployment
AnyLogic	AnyLogic Company	System dynamics analysis, risk analysis, optimization, planning, decision support.	Supply chains, manufacturing, transportation, warehouse operations, rail logistics, mining, oil and gas, ports and terminals, road traffic, passenger terminals, healthcare, business/social processes, asset management, marketing, defense.	Mac, Windows, Linux
Arena	Systems Modelling Corporation	Model verification, analysis of inputs and outputs data, modelling, model verification.	Manufacturing, logistics operations, business processes, supply chain, medicine, military-industrial complex, banks and ATMs, vehicle planning and scheduling.	Windows
FlexSim	FlexSim	Model building, 3D simulation, model analysis, optimization	Manufacturing, material handling, healthcare, warehousing.	Cloud, SaaS, Web-Based, Windows
SIMUL8	SIMUL8	2D process visualisation, workflows animation, business process modelling, the possibility to share simulation and connect to live data sources	Healthcare, manufacturing, automotive, call centres, pharmaceutical chain and logistics, business process management, government and justice.	Cloud, SaaS, Web-Based, Windows
Tecnomatix Plant Simulation	Siemens	Manufacturing, transportation, loading and unloading operations, business process simulation, logistics, sales, scheduling, production rhythm, process verification, supply chain	Discrete manufacturing (automotive, electronics, shipbuilding, machine tools, assembly lines, etc.), logistics, sales, consulting, healthcare, banking.	Cloud, SaaS, Web-Based, Windows
WITNESS	Lanner Group	Manufacturing, optimization, planning, scheduling, business process modelling.	Aerospace, automotive industry, aviation, criminal justice and policing, defense, food sector, healthcare, logistics, manufacturing, nuclear, pharmaceuticals.	Cloud, SaaS, Web-Based, Windows

2.2 Comparative analysis of selected simulation software packages

FlexSim, SIMUL8, Technomatix Plant Simulation and WITNESS offer the most various deployment possibilities in comparison with AnyLogic and Arena.

The studied simulation tools are mainly used by the companies in the following industries:

- industrial machinery, supplies and equipment;
- hospitals and clinics;
- automotive;

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- electronics;
- freight and logistics;
- management;
- aerospace and defense;
- food, beverages and tobacco.

All of the given simulation modelling tools are also used at universities and colleges for educational purposes.

Figure 1 represents the total amount of companies which used and are currently using each of the above mentioned simulation software. The information is provided by the HG Insights Inc. by using their go-to-market intelligence platform [51].

As it can be observed, most companies are currently using Arena simulation software solution and among the studied solutions this software is also the most commonly used one. WITNESS is the least commonly used simulation tool and relatively small number of companies are using it.

Table 3 represents main features of the simulation software packages.

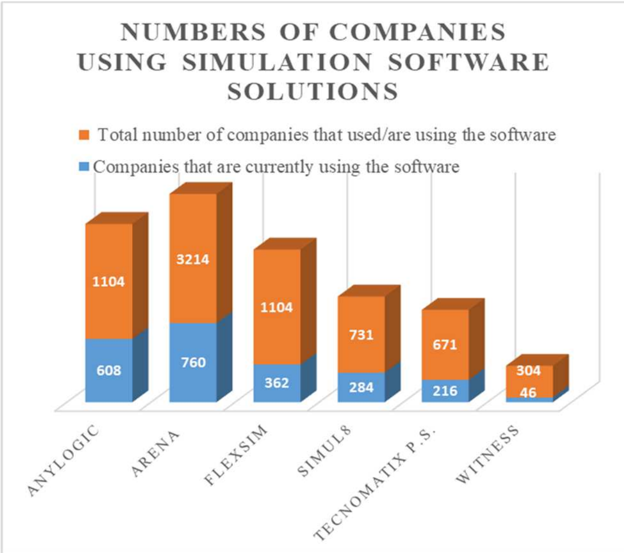

Figure 1 Technology and life

Table 3 Environments oriented towards different approaches in simulation modelling

Software	***AnyLogic***	***Arena***	***FlexSim***	***SIMUL8***	***Tecnomatix Plant Simulation***	***WITNESS***
3D Imaging	✓	✓	✓		✓	✓
Agent-Based Modelling	✓	✓	✓	✓	✓	
Continuous Modelling	✓	✓	✓	✓	✓	✓
Design Analysis	✓	✓	✓		✓	✓
Direct Manipulation	✓	✓	✓	✓	✓	✓
Dynamic Modelling	✓	✓	✓	✓	✓	✓
Graphical Data Presentation	✓	✓	✓	✓	✓	✓
Industry Specific Database			✓	✓	✓	✓
Motion Modelling	✓		✓		✓	
Presentation Tool	✓	✓	✓	✓	✓	✓
Stochastic Modelling	✓		✓	✓	✓	✓

As it can be observed, FlexSim and Tecnomatix Plant Simulation retain all the main features. Grabowik C. et al. [52] made a comparative analysis of simulation results got with these two software simulation packages in order to check how the choice of a software can influence the quality of simulation results. Specific production indexes were taken into consideration and it was proved that the difference between the simulation results was little and thus while selecting between FlexSim and Tecnomatix Plant Simulation other factors such as price, maintenance or interface should be taken into account.

Arena and SIMUL8 offer the least simulation options in comparison with other studied software packages. Using SIMUL8 software one cannot manipulate 2D data into three dimensional format and, since it doesn't offer design analysis option, there is a need of physical prototyping and testing. Also, while using SIMUL8, Arena and WITNESS it is not possible to predict and understand the functional behavior of mechanisms and assemblies, which also causes difficulties in calculating the parameters for mechanical systems due to the lack of modelling motion feature in this programs. AnyLogic and Arena do not have an industry specific database, but Arena also does not have motion and stochastic modelling and without them it is impossible to predict results that take into account certain levels of unpredictability or randomness. Except for not obtaining motion modelling feature, WITNESS simulation software cannot offer agent-based modelling and thus there is no opportunity to examine the behavior of decentralized agents and how such behavior determines the behavior of the entire system as a whole.

3 Conclusion

Many companies are trying to introduce technologies of the fourth industrial revolution into production. Simulation modeling helps to solve the problems associated with the complexity of predicting the effect of changes on production lines, high testing costs in real production conditions and costly correcting deficiencies identified in new products after launch. This scenario assumes the widespread use of various modeling tools for describing and diagnosing systems, as well as conducting pilot projects on predictive modeling, the achievement of which is the ultimate goal. In this paper six discrete-event commercial simulation software packages – Arena, Anylogic, FlexSim, SIMUL8, Tecnomatix Plant Simulation and WITNESS – are described and compared taking into consideration their simulation features and application areas. All of the selected simulation software packages are aimed at analyzing the bottleneck processes, exploring possible “what-if” scenarios, providing “as-is” models, improving the existing systems and they are decision-making tools for enterprises. According to the literature review Tecnomatix Plant Simulation is commonly applied in logistics, manufacturing and engineering industry, FlexSim – in manufacturing and cyber learning, AnyLogic – in vehicle scheduling, pedestrian flow simulation, security systems and digital factories, Arena – in security systems and queueing systems, SIMUL8 – in distribution systems and railway simulation modelling, WITNESS – in assembly and production lines analysis, warehousing, traffic simulation and logistics. FlexSim, SIMUL8, Tecnomatix Plant Simulation and WITNESS offer different deployment alternatives – Cloud, SaaS, Web-Based and Windows, while AnyLogic and Arena offer relatively less amount of the deployment variants. Arena is a most widely used simulation software package among the selected ones and WITNESS is the least commonly used one. As a result of the comparative analysis FlexSim and Tecnomatix Plant Simulations appeared to obtain all the simulation features included in analysis and the main difference may be in price, maintenance or interface. Arena and SIMUL8 offer less simulation opportunities than other studied simulation software packages.

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EFFECT OF NEURAC THERAPY ON PLANTAR PRESSURES DISTRIBUTION AND THE CENTER OF GRAVITY OF THE HUMAN BODY

Monika Michalíková
Department of Biomedical Engineering and measurement, Faculty of Mechanical Engineering, Technical University of Kosice, Letná 1/9, 042 00, Košice, Slovakia, EU, monika.michalikova@tuke.sk (corresponding author)
Lucia Bednarčíková
Department of Biomedical Engineering and measurement, Faculty of Mechanical Engineering, Technical University of Kosice, Letná 1/9, 042 00, Košice, Slovakia, EU, lucia.bednarcikova@tuke.sk
Bibiána Ondrejová
Department of Biomedical Engineering and measurement, Faculty of Mechanical Engineering, Technical University of Kosice, Letná 1/9, 042 00, Košice, Slovakia, EU, bibiana.ondrejova@tuke.sk
Miroslava Barcalová
Department of Physical Education, Technical University of Kosice, Slovakia, miroslava.barcalova@tuke.sk
Jozef Živčák
Department of Biomedical Engineering and measurement, Faculty of Mechanical Engineering, Technical University of Kosice, Letná 1/9, 042 00, Košice, Slovakia, EU, jozef.zivcak@tuke.sk

Keywords: Redcord system, baropodometry, center of gravity, pelvic position, Neurac
Abstract: Nowadays, the pathophysiological posture is a problem for a large part of the population, which leads to a deterioration in the quality of life as a result of functional disorders of the human musculoskeletal system. The aim of the presented article is to point out the effectiveness of movement therapy for the correction of the pelvic position and subsequent adjustment of the body posture, which is evaluated by a change in the distribution of plantar pressures as well as the position of the center of gravity projection. Observations were made on three subjects who reported pain in different areas of the body as a result of incorrect body posture. Input and control measurements were performed on a baropodometer, and Neurac movement therapy in the Redcord system was applied between the individual measurements. The individual exercises were chosen specifically with regard to affect the specific muscle groups. After evaluating the measured data, it can be stated that the selected movement therapy has a significant effect on the correction of pathophysiological position, which is also demonstrated by changing the distribution of plantar pressures, adjusting the position of the center of gravity projection and also significantly eliminating painful symptoms and increasing movement comfort.

1 Introduction

With functional changes of the pelvis, there are postural changes, a deviation of the projection of the center of gravity and a change in the distribution of plantar pressures, which leads to overload and subsequent pain in various areas of the body [1]. Elimination of pelvic dysfunctions can be accomplished through manual medicine and the active Neurac movement method. The purpose of the manual therapy is to deal with special diagnostic and therapeutic procedures that are used for treatment of musculoskeletal reversible functional disorders [2][3]. These are special manual techniques that analyze and localize movement disorders in the area of peripheral and intervertebral joints. The chosen techniques of the individual mobilization that are applied by physiotherapist are determined by the diagnosis, the direction of motion restriction and the type of particular joint. These techniques are used to relieve pain and to mobilize limited movement caused by a reversible functional disorder of the joint or muscles associated with the particular joint [3][4].

The Neurac® (Neuromuscular Activation) treatment method is based on special therapeutically accurate designed exercises in Redcord® devices [5].

The aim of these exercises is to eliminate pain and restore functional motion patterns through high levels of neuromuscular stimulation, while improving muscle harmony and focusing on the cause of problems. These are exercises with bodyweight in all planes and in the unstable environment through the rope [5].

2 Methodology

The measurement was performed in cooperation with physiotherapist Jaroslav Dulina, who has been working in the field of rehabilitation for 15 years. He worked with clients with various degrees of physical ability in a facility equipped with a Redcord system.

The Redcord Therapy System was performed on subjects that went through a basic 5-second static test on a baropodometer and were diagnosed with a functional change in the pelvic position using inspection and palpation. The initial examination was followed by a warm-up consisting of 6 exercises. Selected exercises were performed lying on the back and abdomen (Figure 1) in 3 series of 10 repetitions. Subsequently, they completed another static test and exercise in the Redcord system for 20-30 minutes. Each subject followed the physiotherapist's instructions under his constant supervision.

The aim of the selected exercises was to increase the neuromuscular control and functional stability of the pelvis in the hip area as well as in the torso area. The exercises focused on the dorsal, ventral and lateral myofascial chains. The indications were impaired neuromuscular control, impaired functional stability, decreased or painful range of motion, fatigue, stiffness, discomfort or pain [5].

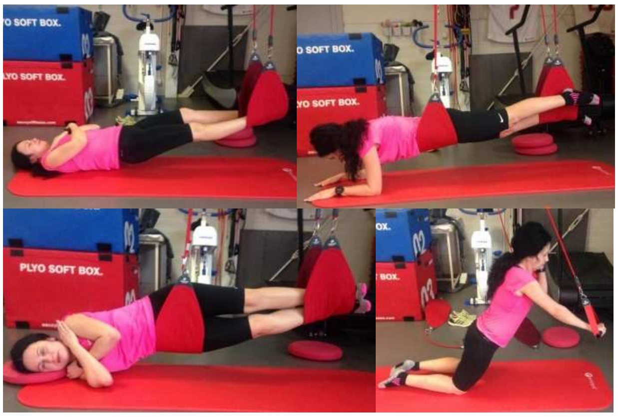


Figure 1 Exercises performed in the Redcord system

After completing the exercises in the Redcord system, a static output test was performed on a baropodometer, following the methodology as in the previous measurements (Figure 2).

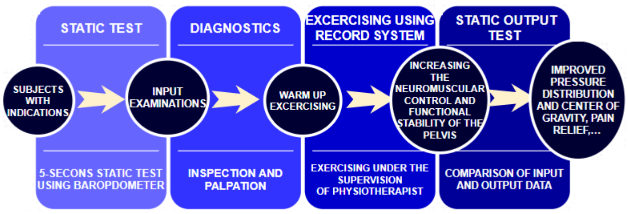


Figure 2 Measurement procedure

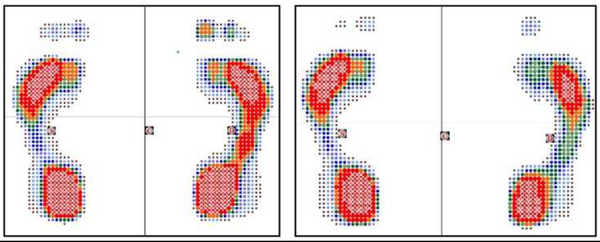
Pedobarometry use computer-processed data from pressure sensors, which inform about the load on the foot during standing or other activities. The pressure sensors have the shape of matrix that measure the force acting on the element of the matrix. Sensors allow accurate real-time sensing and analysis of pressure distribution on the foot in a standing position (static test) and during walking (dynamic test). During the static test, overloaded areas are located, including the projection of the maximum compressive force on the soles of the feet. The distribution of the load between the left and right lower limb is evaluated and compared areas of the support are measured between the forefoot and the hindfoot part of each limb. The position of the center of gravity and the center of the loading forces on the left and right lower limbs are also recorded.

3 Results

3.1 *Subject 1*

A 43-year-old man, an active motorcycle rider who regularly practices 2-3 times a week. In the past, a professional football player who ended his career due to surgery of groin. The subject had persistent knee problems and in the past he had a broken vertebrae, collarbone and arm, and underwent spinal surgery.

An initial measurement on a baropodometer revealed an overload of the middle part of the right foot, which was related to pain in the left groin. After the warm-up, the contracted muscles relaxed. Subsequently, the subject completed 4 exercises in the Redcord system in the period of 25-30 minutes, during which he had some problems with their correct exercising. It was not necessary due to use of auxiliary straps or ropes. In the output measurement, the test was run without the subject's knowledge, so that the results were not affected by his active correction.



	Before exercises		After exercises	
Frontfoot	Sx	Dx	Sx	Dx
Surface (cm^2)	75,25	80,25	68,75	65,50
Load (%)	22,4	24,5	25,3	22,5
Ratio HF (%)	49,1	45,1	50,0	45,5
Hindfoot	Sx	Dx	Sx	Dx
Surface (cm^2)	79,50	92,25	69,75	75,22
Load (%)	23,2	29,9	25,3	26,9
Ratio HF (%)	50,9	54,9	50,0	54,5
Total	Sx	Dx	Sx	Dx
Surface (cm^2)	154,75	172,50	138,50	140,50
Load (%)	47,3	52,7	49,6	50,4

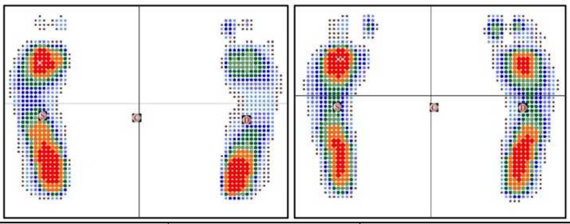
Figure 3 Static test of the 1st subject (before therapy, after movement therapy)

It is noticeable (Figure 3) that the position of the center of gravity has been adjusted and an even distribution of the body weight has been ensured. On the right foot, the midfoot part is correctly lightened, which was overloaded before the exercise. From a biomechanical point of view the overload of midfoot part could cause limitation of the function of the longitudinal arch during walking. The pressure distribution between the right and left lower limbs also clearly improved.

3.2 Subject 2

A 40-year-old female subject with left hindfoot pain, who has never played professional sports. She has a sedentary job and started running actively 2 years ago. It runs 4-5 times a week for 1-1.5 hours at a free pace.

The initial static test confirmed the overload of the left leg, especially in the heel area, complete relief of the forefoot, rotation of the pelvis from left to right as well as rotation of the pelvis downwards on the left side. As a result of this overload, there were increased impacts in the area of the Achilles tendon caused by the minimal support of the 1st and 2nd fingers and the complete absence of the support of 3-5 fingers. Subsequently, the subject proceeded to the exercise in the Redcord system, where 4 exercises were performed in 4 series of 10 repetitions. The subject was able to perform the exercises only after changing the suspension point, which caused the extension of the exercise and it took about 30-35 minutes. Subsequently, an output static test was performed.



	Before exercises		After exercises	
Frontfoot	Sx	Dx	Sx	Dx
Surface (cm^2)	53,50	53,00	54,25	60,50
Load (%)	23,0	18,5	22,2	23,5
Ratio HF (%)	42,6	40,1	46,3	45,1
Hindfoot	Sx	Dx	Sx	Dx
Surface (cm^2)	65,00	64,00	58,00	64,50
Load (%)	30,9	27,6	25,7	28,6
Ratio HF (%)	57,4	59,9	53,7	54,9
Total	Sx	Dx	Sx	Dx
Surface (cm^2)	118,50	117,00	112,25	125,00
Load (%)	50,3	49,7	47,3	52,7

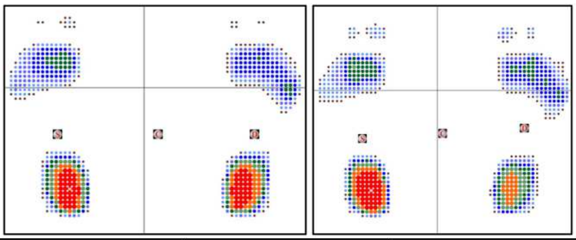
Figure 4 Static test of the 2nd subject (before therapy, after movement therapy)

The image shows (Figure 4) a visible change in the load, which was transferred from the heel to the forefoot and ensured an increase in stability with a demonstrable support, especially in the area of the 1st and 2nd toe. For the subject, it would be appropriate to further incorporate exercises to enhance the longitudinal arch and correct the adductive position of the forefoot.

3.3 Subject 3

The subject is female, has a sedentary job and suffers from right wrist pain. The subject's medical history is a carpal tunnel. In the past, she had a fracture of her left collarbone caused by a fall from a horse. The subject was diagnosed with pelvic rotation and severe spinal scoliosis during the first exercise.

The first static test did not show a change in the load on the feet but a deviation of the center of gravity, which was caused by scoliosis of the spine and rotation of the pelvis. The subject has a fairly high arch of the foot. Due to the large number of postural dysfunctions, the exercise was focused only on a certain part, which ultimately was to eliminate scoliosis. The elimination of the scoliosis should be reflected in the change of plantar pressures and in a better location of the center of gravity. After exercises in the Redcord system, the scoliosis of the spine was adjusted and the right shoulder was raised as the pain radiated to the right hand.



	Before exercises		After exercises	
Frontfoot	Sx	Dx	Sx	Dx
Surface (cm^2)	38,00	37,75	36,75	38,75
Load (%)	19,2	18,8	18,7	20,2
Ratio HF (%)	39,3	36,9	37,0	40,7
Hindfoot	Sx	Dx	Sx	Dx
Surface (cm^2)	41,25	45,25	43,50	48,00
Load (%)	29,8	32,2	31,8	29,3
Ratio HF (%)	60,7	63,1	63,0	59,3
Total	Sx	Dx	Sx	Dx
Surface (cm^2)	79,25	83,00	80,25	86,75
Load (%)	48,8	51,2	48,1	51,9

Figure 5 Static test of the 3rd subject (before therapy, after movement therapy)

In the second image (Figure 5), a slight improvement in stability is seen through the tread of the fingers. The corrected position of the center of gravity projection is also clearly visible. The subject felt pain relief after the first exercise. After 10 exercises of 40 minutes, the pain was removed. It is advisable to continue stretching exercises in the leg area as well as the entire lower limb in order to relax the contracted muscles. Subsequently, the symptoms of the high arch are expected to alleviate as well as restoration of functional biomechanical aspects of the foot.

4 Discussion

The obtained results show that Neurac therapy is suitable for correcting the distribution of plantar pressures as well as influencing the position of the center of gravity, but it would be appropriate to expand the monitored group of subjects. Furthermore, it would be appropriate to monitor the long-term effect of the therapy by supplementing the measurements with time intervals (for example, one month, three months and a half years after the end of the therapy). The proposed measurement procedure can also be used to check the effectiveness of other types of movement therapy. Static measurement should also be supplemented by stabilometry and dynamic test, which would indicate dynamic parameters such as step cycle symmetry on the right and left side, step width adjustment, velocity and trajectory of center of gravity oscillations, anteroposterior and lateral deviations. From these parameters, it would be possible to evaluate the effect of movement therapy on improving the stability of the subject.

5 Conclusions

The application of the Neurac method, which consists in the restoration of functional movement patterns through neuromuscular stimulation, adjusted the position of the center of gravity of the monitored subjects with a change in pelvic position. Using the Redcord system and the subsequent evaluation of static baropodometric tests, there are determined following conclusions, which are recommended to be observed for successfully correction of the center of gravity.

Before exercising with the Redcord system, it is important to warm up to prevent from possible injury or muscle fever. Proper performance of the exercises also plays an important role in preventing incorrect posture habits, especially in adolescence. In evaluating this method, the importance of compensatory exercises performed after fitness exercise was also pointed out.

In conclusion, it is worth noting that despite the low number of examined subjects, the effectiveness of the applied method is high and therefore it can be recommended as an effective method of solving the deviation of the center of gravity in functional changes of the pelvis.

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NUMERICAL SIMULATION OF ECCENTRICITY CREATION IN THE PRODUCTION OF HOT ROLLED TUBES

Roman Ďurčík
ŽP Research and Development Centre Ltd., Kolkáreň 35, 976 81 Podbrezová, Slovak Republic, EU, durcik.roman@zelpo.sk
Ladislav Morovič
Slovak University of Technology in Bratislava, Faculty of Materials Science and Technology in Trnava, Institute of Production Technologies, Department of Machining and Computer Aided Technologies, Jána Bottu 2781/25, 917 24 Trnava, Slovak Republic, EU, ladislav.morovic@stuba.sk (corresponding author)
Michal Kán
ŽP Research and Development Centre Ltd., Kolkáreň 35, 976 81 Podbrezová, Slovak Republic, EU, kan.michal@zelpo.sk
Milan Mojžiš
ŽP Research and Development Centre Ltd., Kolkáreň 35, 976 81 Podbrezová, Slovak Republic, EU, mojzis.milan@zelpo.sk

Keywords: eccentricity, piercing press, tube, numerical simulation, DEFORM-3D

Abstract: The paper deals with the issue of eccentricity in the technological node of the piercing press, under selected conditions, which result from the possibilities of production in the conditions of ŽP a.s. These conditions were verified and adapted to the rolling process. This process consisting of individual technological nodes on the rolling mill, in which eccentricity is created on the piercing press and the following steps eliminate it in other technological nodes. For quality analysis of manufacturing tubes using numerical simulation, it is necessary to know the actual state of eccentricity creation on the rolling mill. A numerical simulation of piercing under different input conditions was used (software DEFORM-3D) and was performed for several different charge states before entering onto the piercing press. The eccentricity itself has a significant effect on the resulting geometric quality of the tubes.

1 Introduction

The dimensions of the tubes belong to the basic characteristics of the tubes. For the needs of industry and general use, tubes with diameters from tenths of a millimetre to tubes with a diameter of few tens of centimeters are produced. The dimensions of the tube must be given in such a way as to fully identify the tube in this respect. In addition to length, three main dimensions stand out for tubes with a circular cross-section: outer diameter, inner diameter and wall thickness.

1.1 Shape and Dimensional Defects of Tubes

When rolling tubes on rolling mills, defects on the surface of the tubes can occur at various stages of rolling for various reasons.

Rolled tube defects can be divided (classified) into 3 basic groups of errors:

- Shape and dimensional defects.
- External surface defects.
- Internal surface defects.

One of the problems in hot rolling (which the paper will also address) is the eccentricity on the piercing press. In essence, this is a specific form of tubes defects causing wall thickness unevenness.

Eccentricity is a measure (degree, volume, extent) of the difference between the centers of the outer and inner diameters. Eccentricity is allowed within the wall thickness tolerances and is calculated from the wall thicknesses in one cross section.

1.2 Causes of Eccentricity Creation

The main cause of eccentricity creation can be considered the non-concentrated piercing of the billet on the vertical piercing press, which can be caused by the following factors:

- Cutting process of batch preparation.
- Billet geometry.
- Uneven heating of the billets in the rotary hearth furnace.
- Incorrect calibration of the billet, which will cause poor chamfering quality of the billet´s edges in calibration duo.
- Non-coaxial movement of the piercing mandrel with respect to the die axis.

The literature [1-10] deals with the issue of pipe eccentricity (from the point of view of analysis, prediction, monitoring, numerical modeling and measurement) at various technological nodes and materials.

2 Methodology

2.1 *Eccentricity Calculation Method*

The method for calculating the eccentricity dimension (1) in drawn-reduced tubes is as follows (Figure 1):

$$E = \frac{S_{max} - S_{min}}{S_{max} + S_{min}} * 100\ \% \qquad (1)$$

S_{min} - minimum value of tube wall thickness in one cross section (mm),

S_{max} - maximum value of tube wall thickness (mm) (opposite to minimum wall thickness).

2.2 *Eccentricity Simulation in the Piercing Press*

In the paper, the main attention is paid to the piercing press, where the primary reason for the occurrence of eccentricity is assumed by off-centering the mandrel of the piercing press when it is pressed into the material. Three presumed effects on eccentricity were selected and simulated, namely:

- the effect of poor cutting surface,
- uneven billet temperature distribution when heating in the rotary hearth furnace,
- off-centering of the billet in the die.

All previous operations were included in the models, in the case of uneven heat distribution in the billet also the course of heating in the furnace. The elastic model of the mandrel with predefined elastic properties of the material (Young's modulus, Poisson's constant) was used to monitor the mandrel deflection. In the analysis, the main deflection of the mandrel in the X axis was monitored (the Z axis was chosen as the mandrel axis).

This task also focused on the validation of the model of thermal quantities with experimental measurements directly on the mill.

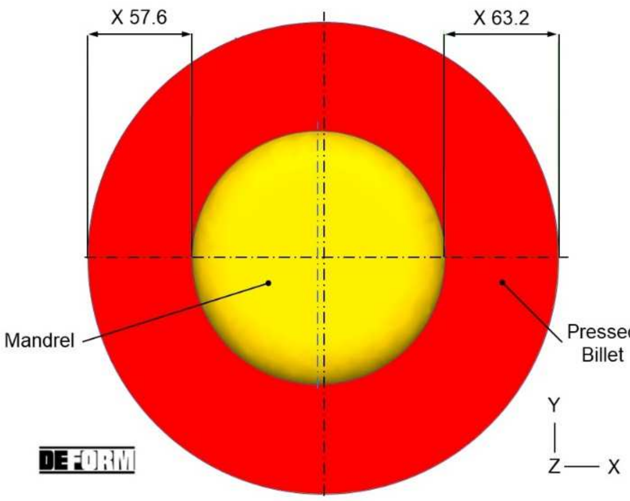

Figure 1 Eccentricity on pressed billet

2.3 *Input Data for Simulation*

Billet with diameter of Ø205 mm, fillet of R40 mm, length of 1020 mm and a number of 260 000 elements was used as an input model for all simulations (Figure 2). The size of the elements itself was set from 1 mm to 10 mm and the given refinement was used in places according to the necessity of the monitored quantities. An elastic mandrel having 60 000 elements with given elastic properties was used to analyze the eccentricity in the piercing simulation. Table 1 shows the main input data used for the simulation.

Table 1 Main input data for simulation

Number of billet elements	260 000
Billet material	E355
Number of mandrel elements	60 000
Poison´s constant of the mandrel	0.3
Young´s modul of the mandrel	210 000 MPa
Thermal conductivity of the hearth	(Figure 3) W/mK
Heat capacity of the hearth	1.07 N/mm^2/K

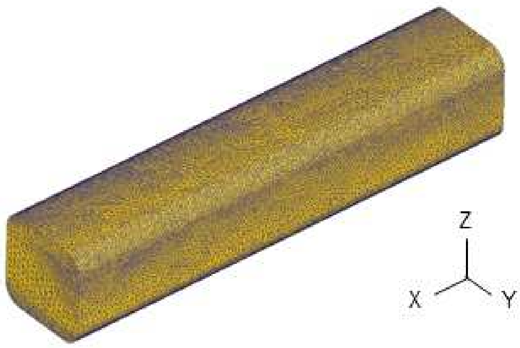

Figure 2 The used finite element model of the billet

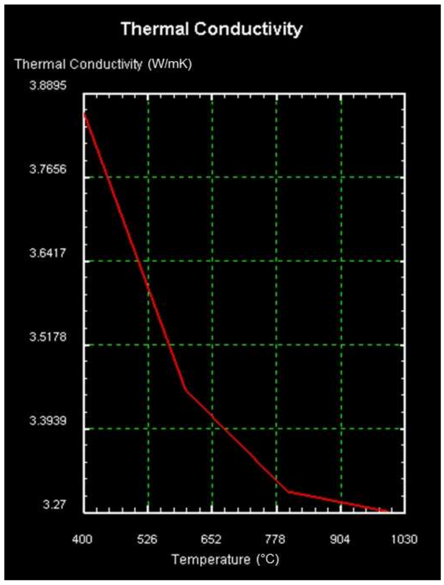

Figure 3 Thermal conductivity of the hearth

3 Results and Discussion

3.1 Uneven Heat Distribution

In this task, the billet was simulated for heating in a rotary hearth furnace. The main goal was to monitor the effect of the heat gradient along the height of the billet on the eccentricity of the piercing where the surface of the billet, which is in contact with the hearth of the furnace, has a lower temperature than the free surface on the opposite side (Figure 4). The temperature on the upper side (point 1) reached 1275 °C, on the middle of the billet (point 2) 1278 °C and on the hearth side (point 3) 1265 °C. The resulting difference between the temperatures on the sides of the charge is thus 10 °C.

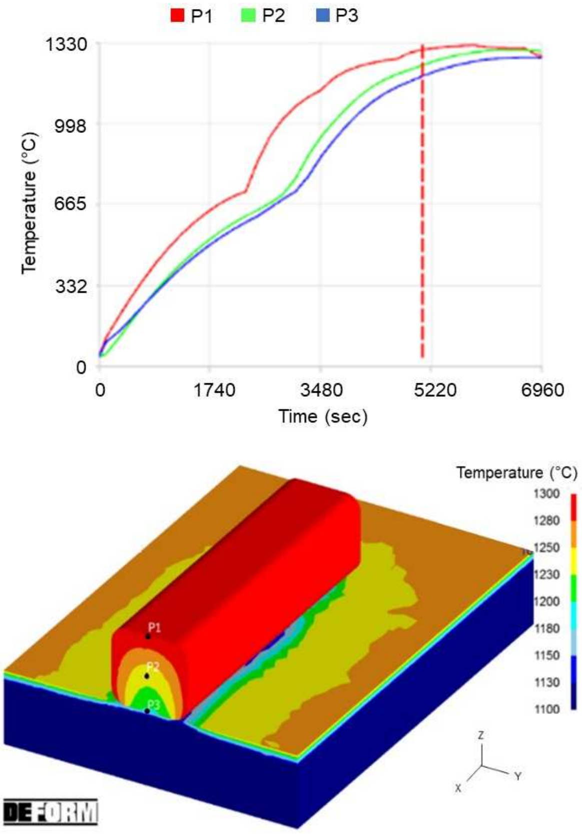

Figure 4 Heating of the billet in the rotary hearth furnace (approx. 1.5 hours)

The temperature difference before the piercing on the opposite sides of the charge was not significant (approx. 9 °C). This difference is similar to the output of the rotary hearth furnace (Figure 5). Also the temperature in the middle of the billet is the same (Figure 6).

The Figure 7 shows the course of the deflection of the axis of the mandrel along the length of the pressed billet. The selected point was on the surface in the center of the mandrel head. It can be stated that the mandrel was gradually pushed to the side with a higher temperature and reached a deviation from the axis by approx. 0.8 mm. For this reason, it can be stated that the uneven distribution of heat across the cross section in this case does not have a significant effect on the resulting eccentricity.

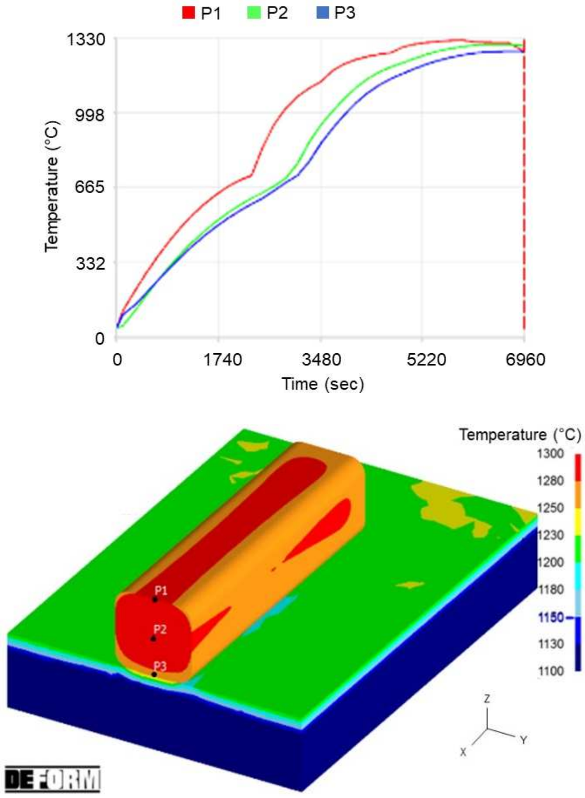

Figure 5 Heating of the billet in the rotary hearth furnace (output from the furnace)

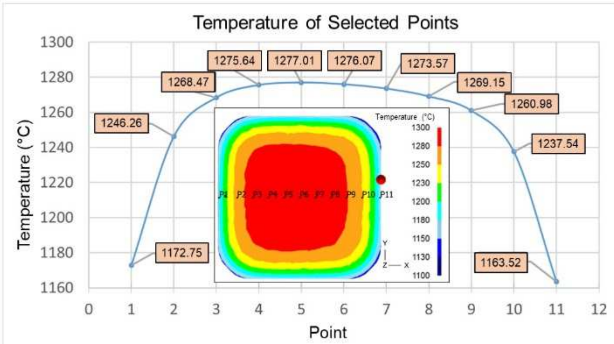

Figure 6 Temperatures in section before piercing

Heat dissipation to the conveyor rollers was not included in the models. For this reason, the border situation was also simulated, where directly before the piercing press the condition of difference approx. 50 °C on the sides of the billet was set (Figure 8).

The Figure 9 shows the entire piercing process of such a billet. A higher eccentricity is already visible here, where the deflection of the mandrel axis has reached a value of 3.9 mm.

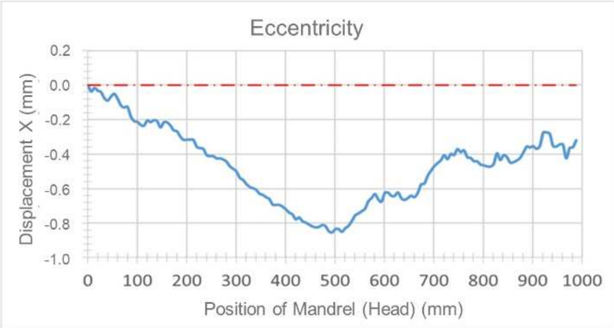

Figure 7 Eccentricity at the distance of the center of the mandrel head from the beginning of piercing (difference of 10 °C)

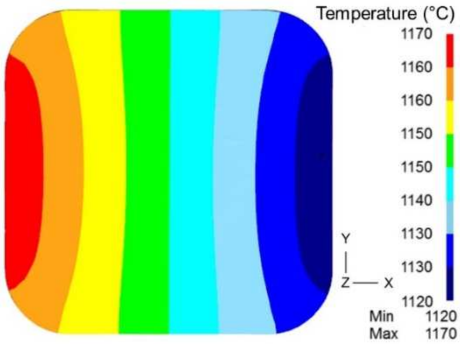

Figure 8 Temperatures in cross-section of the billet before piercing

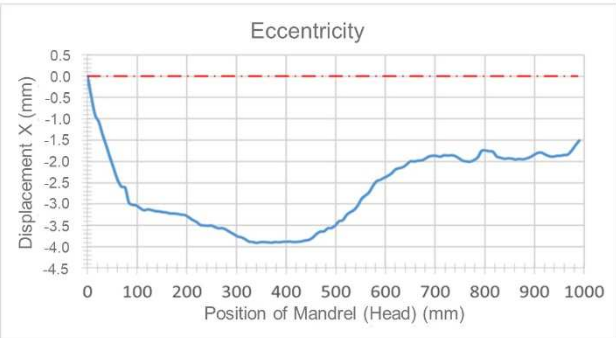

Figure 9 Eccentricity at the distance of the center of the mandrel head from the beginning of piercing (difference of 10 °C)

3.2 *Off-Axis Centering*

In this model, the charge was calibrated 10 mm more than the ideal calibration. This means that the diagonal of the billet was 10 mm less along its entire length, which allowed us to tilt the axis of the billet in the die by 0.7° relative to the axis of the mandrel (Figure 10). All previous operations before the piercing were included in the model. For the simulation, the charge had a constant temperature of 1260 °C before transport to the descaling. As can be seen from the course in Figure 11, the axis of the mandrel deviated to 5.3 mm at the beginning of the piercing . In the following course, the mandrel returned to its original value.

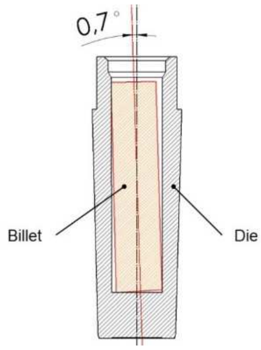

Figure 10 Informative example of charge (billet) tilt in the die

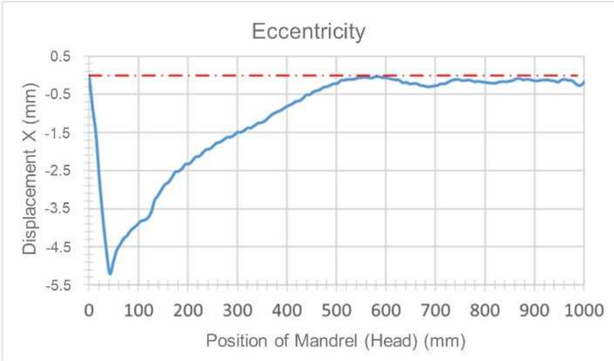

Figure 11 Eccentricity at the distance of the center of the mandrel head from the beginning of piercing (off-axis centering)

3.3 *Cutting Surface*

A billet model was created where one side of the billet was 10 mm longer, so a bevel was created on the top of the billet. For the simulation, the charge had a constant temperature of 1260 °C before transport to the descaling. As can be seen from the course in Figure 12 the axis of the mandrel deflected again to the value of 2.4 mm at the beginning of the piercing and in the following course the mandrel returned to its original value.

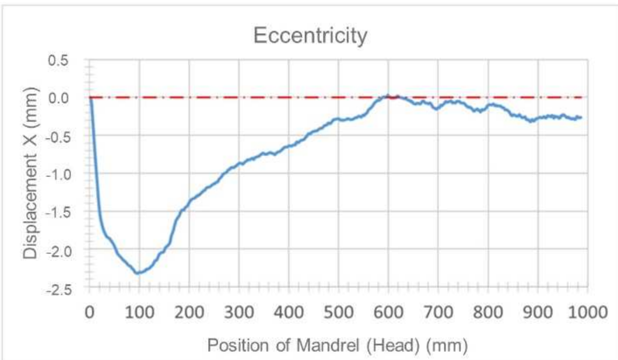

Figure 12 Eccentricity at the distance of the center of the mandrel head from the beginning of piercing (on cutting surface)

4 Conclusion

The simulations themselves were aimed at determining the individual effect of factors what (uneven heat distribution, off-axis centering, cutting surface) on the eccentricity creating. In real conditions, however, it is a combination of several factors on the resulting eccentricity.

Based on the achieved results, it is possible to state that the highest degree of off-centering of the mandrel (and thus the eccentricity creation) is mainly at the wrong centering of the billet in the die of the piercing press. Here, the feed of the mandrel compared to the piercing axis is up to 5.3 mm and the resulting eccentricity of the molding is at the level of 8.8% even in a small section of approx. 50 mm from the start of piercing. Also, the mandrel itself can partially eliminate this eccentricity in the upper part by further movement. Moreover, we cannot accurately assess this state of offset centering in real conditions.

The simulation of the uneven heat distribution at the cross-section of the billet did not show a significant effect on the eccentricity at difference of 10 °C between the lower and upper side after leaving the furnace. However, at a gradient of 1120 °C → 1170 °C (difference of 50 °C), the eccentricity on the molding reached 3.9 %. We assume that under operating conditions, this state can only occur if the billet is stayed on the conveyor for a longer period before piercing. The course between the simulations is similar, where the mandrel after the maximum deflection gradually returns approximately) to the half position between the maximum deflection and the die axis.

In Table 2 are the results of the maximum eccentricity in the individual simulations.

Table 2 Eccentricity results for individual factors

Factor	Eccentricity
Uneven heat distribution	1.4 %
Uneven heat distribution at difference of 50 °C	3.9 %
Offset centering	8.8 %
Cutting surface	4.1 %

It is important to note that all piercing models in the simulation were set as the ideal state, i.e. ideal mandrel exactly in the middle of the axis without the possibility of tilting in the upper position and with regular running.

According to the obtained results and research findings presented in the paper, the installation of a measuring system for monitoring the off-centering the piercing mandrel in the piercing press would be appropriate to eliminate the eccentricity. Based on the measurement results, the piercing mandrel would be set up or replaced. A suitable solution for measurement could be the design of a non-contact measuring system for measure off-centering the piercing mandrel in the piercing press, what the authors of the article consider a reasonable future continuation of the work and research.

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THE COMPARISON OF THE DYNAMIC TESTS RESULTS FROM SENSORY PLATFORMS

Monika Michalíková
Department of Biomedical Engineering and measurement, Faculty of Mechanical Engineering, Technical University of Kosice, Letná 1/9, 042 00, Košice, Slovakia, EU, monika.michalikova@tuke.sk (corresponding author)
Lucia Bednarčíková
Department of Biomedical Engineering and measurement, Faculty of Mechanical Engineering, Technical University of Kosice, Letná 1/9, 042 00, Košice, Slovakia, EU, lucia.bednarcikova@tuke.sk
Richard Staško
Department of Biomedical Engineering and measurement, Faculty of Mechanical Engineering, Technical University of Kosice, Letná 1/9, 042 00, Košice, Slovakia, EU, staskorichard@gmail.com
Jozef Živčák
Department of Biomedical Engineering and measurement, Faculty of Mechanical Engineering, Technical University of Kosice, Letná 1/9, 042 00, Košice, Slovakia, EU, jozef.zivcak@tuke.sk

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Abstract: The article deals with dynamic plantography, which is a popular diagnostic method focused on assessment of the foot condition during walking and to expose foot disorders. The aim of the paper is to discover whether it's possible to do dynamic analyses on short platforms by using comparison of short and long sensory platform output. To get dynamic output were used ImportaMedica platforms, specific long platform Elegance and short platform Speed. Three subjects were involved in dynamic test on both platforms. The evaluated parameters were surface of the foot, maximum and average pressure, speed and gait line. By comparing these parameters the biggest difference was discovered in adapting walking because of the correct tread on short platform. When comparing the outputs from the long and short platforms, a longer duration of the right and left footsteps was recorded for all three subjects on the short platform.

1 Introduction

Dynamic plantography is a method of examining the plantar aspect of the foot using a pressure platform, a sensory treadmill or sensory insoles for shoes. This is a measurement of the pressure distribution under the sole of the foot, usually during walking. The measurement is performed in real time, while the values of the monitored parameters change. This method has its clinical application in fields such as orthopedics, rehabilitation, neurology, prosthetics and orthotics, but also in sports medicine and training.

At present, this method of examination is increasingly sought after and there are several sensory platforms on the market of various sizes and variations enabling dynamic analysis. Nowdays, even short platforms designed for static analysis of the sole of the foot are extended with the possibility of dynamic analysis. Since it is necessary to take a step in such an analysis and obtain a record of both feet, it is speculated whether short platforms are suitable for this type of measurement. The aim of the presented article is to compare the outputs obtained from the short and long platform and to find out their coherence.

2 Methodology

The measurement was performed in cooperation with Ing. Darina Kuštánová, MiopeD s.r.o. and Impronta Medica s.r.l.

The measurement was performed on a short Speed platform (resolution 4/16 sensors / cm², sensing area dimensions 400 x 550 mm, selectable collection frequency 5-600 Hz) and a long Elegance platform (resolution 4/16 sensors / cm², sensing area dimensions 1600 x 550 mm, optional collection frequency 5-400 Hz) from Improta Medica (Figure 1).

Figure 1 Elegance long platform (top) and Speed short platform (bottom)

Sensor platforms and walk path must be placed in the middle of the room because of the sufficient space for movement in front of and behind them. It is advisable to align these platforms with the floor for more accurate measurement and to avoid the risk of the subject adapting his gait to step on the equipment instead of walking naturally. Therefore, the inactive part of the pavement should be made of a similar material as the active one.

Three healthy subjects were evaluated (Table 1) and the monitored parameters are foot area, speed, maximum and average pressure and rolling curve.

Table 1 Basic data of measured subjects

	Gender	High (cm)	Weight (kg)	Shoe size (cm)	Age
Subject 1	Female	165	50	24	23
Subject 2	Female	162	45	25	45
Subject 3	Male	174	64	28	41

For the relevance of the measurement, it is necessary that the measured subjects are informed of certain principles before performing the test. Getting enough sleep is especially important, which is at least 6-8 hours of sleep. Subjects should undergo the measurement rested and relaxed, so they should not perform any physically or mentally strenuous activities prior to the measurement. At the time of measurement, it is important to have suitable, comfortable clothing that does not limit the natural movement.

At the beginning of the measurement, the subject is informed about the measurement process. To achieve reliable results, it is necessary for the subject to get used to walking on platforms on a 5-minute walk. It is necessary to pay attention to the footprint of the entire foot on the sensor platform, therefore it is necessary to perform test experiments during the measurement, during which the track and its beginning are individually adjusted. The subject should not know where the active platform is located so as not to adapt his step cycle to the correct tread on the platform [1].

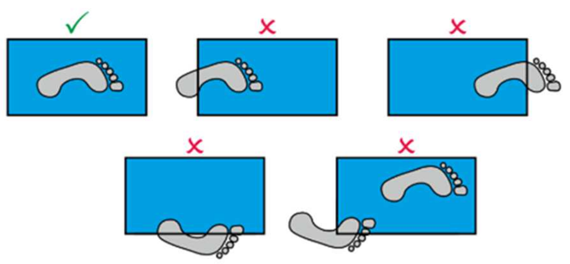

Figure 2 Examples of correct and incorrect foot position on the platform [1]

The posture of the subject should be with the hands moving freely along the body. Testing takes place during natural walking speed. The number of steps taken before the sole of the foot comes into contact with the platform is standardized, as research suggests that the number of steps performed before contact with the platform may affect the recorded pressure values [2].

If the measurement is performed on a short platform, the measurement must be performed for both feet so that the subject first performs the measurement with one foot stepped on the platform and then repeats the measurement with the other foot stepped on the platform. The subject must always step on the platform from the same side. This means that after performing the first measurement, it bypasses the platform and repeats the measurement in the same direction as the first.

3 Results

In all three cases, reports from the short and long platforms were evaluated, which contained the following monitored parameters.

3.1 *Foot contact area*

It is conditioned by the shape of the arch of the foot and full contact of the foot with the platform occurs in a normal foot only on the lateral tent of the sole. It can be determined as the area of active pressure points detected on the foot and is expressed in cm^2. Because of it, it is possible to determine the morphological changes of the feet, for example, flat feet. The size of the area should be similar for both feet, so the difference between the area of the left and right foot is also monitored, which indicates an uneven loading of the feet.

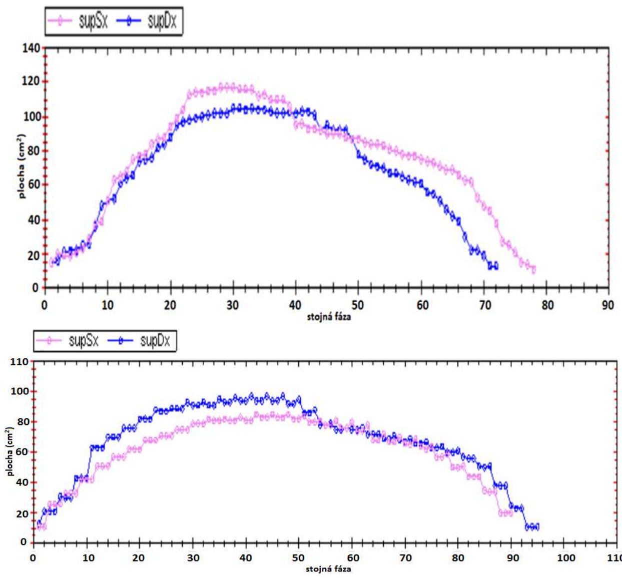

Figure 3 Graph of foot area on a long (top) and short (bottom) platform

3.2 *Step velocity in the standing phase*

A lower stride velocity is usually associated with the back of the foot, increases in the middle and then decreases in the front of the foot. As you lift your foot and move on to the next step, the velocity of the step increases again.

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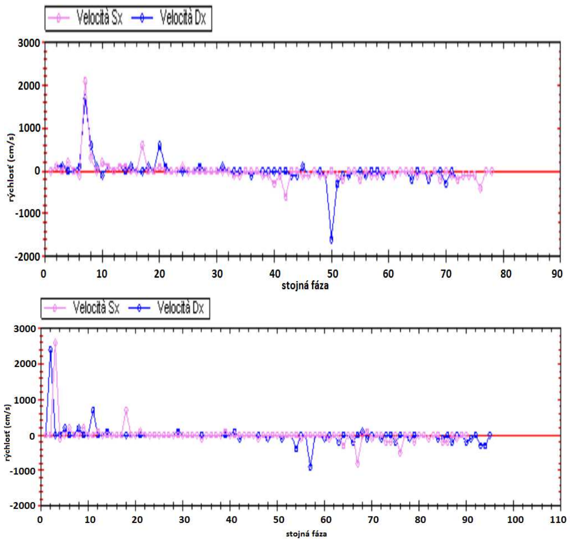

Figure 4 Graph of step velocity on a long (top) and short (bottom) platform

3.3 Maximum and average pressure

The pressure, its changes over time and its distribution in the measured area are among the basic parameters of dynamic plantography. These are directly measured parameters from which other parameters can be calculated. The maximum pressure corresponds to the value of the point with the measured maximum pressure in the sensing area. The average pressure is defined as the pressure value corresponding to the average pressure measured on the evaluated area. In the graphical display, the pressure values are displayed as a line of points of maximum load that were recorded during the dynamic analysis. The curve of this graph should rise at normal values in the middle part and slightly decrease at the end of the graph. The curve of the average pressure value shows the line of the recorded mean pressure.

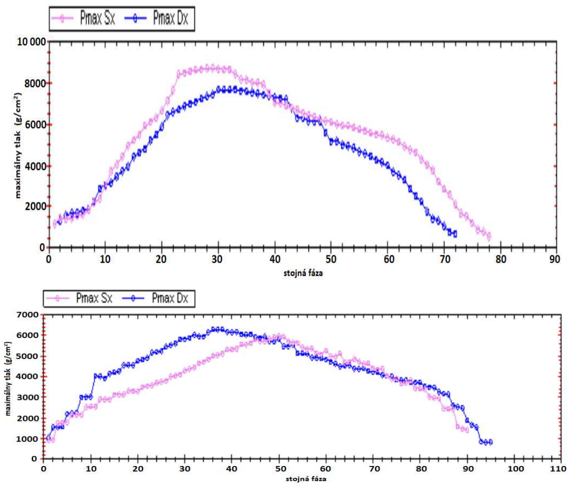

Figure 5 Graph of maximum pressure on a long (top) and short (bottom) platform

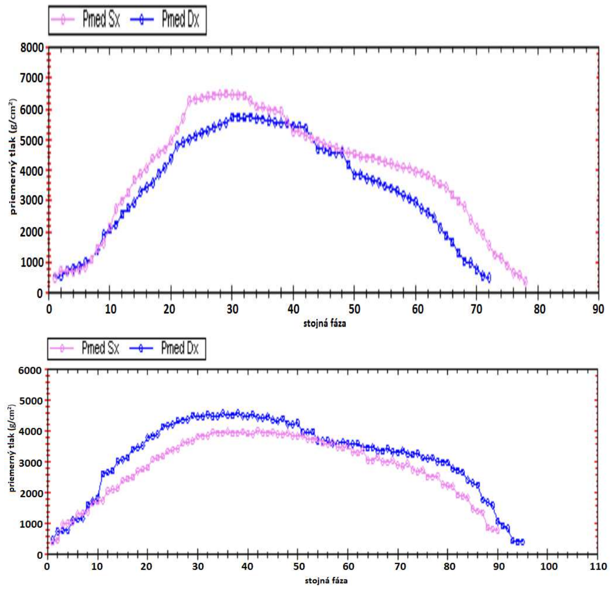

Figure 6 Graph of average pressure on a long (top) and short (bottom) platform

3.4 COP gait line

The center of pressure (COP) gait line is a visual expression of the part of gait during which the foot is in contact with the ground. It takes into account where all contact pressure points are and what their values are. It is represented by the aggregate of pressure dots which are plotted with respect to time and at a specific sample rate [3].

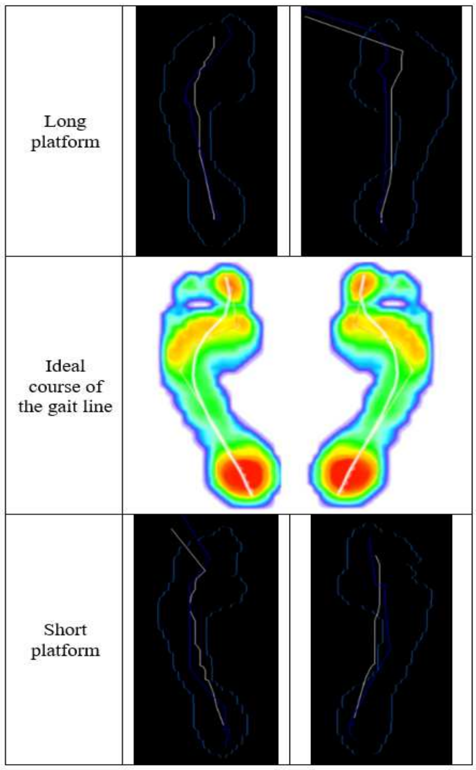

Figure 7 Recorded COP gait lines

The physiological COP gait line should be starting at the third of the rearfoot, continuing towards the 5th metatarsal, then proceeding centrally to the 4th metatarsus, then to the 3rd to 2nd metatarsi and ending at the toe of the foot, as it is the last in contact with platform.

4 Discussion

When comparing the outputs from the long and short platforms, a longer duration of the right and left footsteps was recorded for all three subjects on the short platform. The reason for this phenomenon may be the effort of the subjects to step on the platform and adapt their gait to this goal.

In the case of the 1st and 3rd subjects, a higher maximum pressure was measured on a long platform. This can cause faster walking during long platform measurements. From the comparison of the number of standing phase shots also in the case of the 2nd subject, the duration of the step of both feet on a long platform was shorter, which indicates a higher walking speed, which is associated with higher pressure on the sole of the foot. In this case, however, a higher maximum pressure was recorded on the short platform. The reason for this phenomenon may be that the curves of the maximum pressure graph are too irregular.

The short platform has significant limitations in dynamic analysis - it is not possible to evaluate basic walking parameters such as step length, step width, step cycle symmetry on the right and left side.

5 Conclusions

The aim of the presented study was to compare dynamic records obtained from 2 different sub-parametric devices. Specifically, from the long and short sensor platform, in order to verify the reality of the outputs obtained from the short sensor platform due to doubts about the possibility of correct dynamic analysis on devices designed primarily for static and stabilometric analysis.

The smallest difference between the long and short platform in the length of the step was in the 1st subject, on the contrary, the largest difference was in the 3rd subject.

A higher maximum pressure was measured on a long platform (1st and 3rd subjects).

By comparing the two platforms, higher values of the average pressure in all 3 cases were recorded on the long platform.

When comparing the rolling curves of the 1st subject, a greater instability of the foot was recorded when measuring on a short platform. Also, the end of the rolling curve of the left foot was recorded on the short platform already in the area of the 3rd metatarsal, while on the long platform the curve continued until the 2nd toe. On the plantogram from the long platform, all the fingers were clearly visible, while on the short platform the fingers are not so smoothly recorded. Also on a short platform, the pressure of the right foot is more concentrated on the heel, while on a long platform it is more in front of the foot.

In the case of both platforms, there is a similarity between the rolling curves of the 2nd subject, mainly in the back and middle part of the foot. On a long platform, the curves of both feet end more medially than in the case of a short platform. Similarly, an incorrect course of the rolling curve is recorded on both platforms. The curves obtained from the short platform have a slightly more non-linear shape, which means greater instability. Fingers are not recorded on the planks of the short platform except the thumb, while on the long platform the fingers are visible.

The 3rd subject had the smoothest course of rolling curves. Although even in this case their course differed slightly from the physiological course of the rolling curve of both platforms, there is considerable similarity between the curves from the long and short platform. Except for the thumb, the toes are only slightly present on the plantograms from both platforms.

After processing and comparing the parameters, it was found that the main shortcoming of the dynamic test on short platforms is the subject's effort to properly step on the platform, which has an impact on the natural course of walking subjects. This results in a slower gait, i.e., a longer standing phase duration and a higher recorded maximum pressure. Also, when measuring on a short platform, greater instability of the foot may occur.

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