Application of Zebris dynamometric platform and arch index in assessment of the longitudinal arch of the foot

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Abstract.

BACKGROUND: Assessment of the foot arch is an important element of posture examination. In clinical practice, different methods are used. Reliability and repeatability of the techniques raises many doubts.

OBJECTIVE: Development and verification of our own, automated diagnostic algorithm for evaluation of the longitudinal arch of the foot with the use of the Zebris FDM-S dynamometric platform.

METHODS: This paper presents selected footprints assessment methods and Zebris dynamometric platform to assess the longitudinal arch of the foot.

RESULTS: The results were compared to standard plantography examination. The outcomes show high correlation of the investigated parameters methods used. The ambiguity of classification criteria of foot arch was observed.

CONCLUSIONS: 1/Examination confirmed strong linear correlation between the Arch Index results obtained during examination on a stabilometric platform and plantography examination. 2/The proposed algorithm for AI evaluation using the Zebris FDM-S dynamometric platform enables simultaneous analysis of stabilometric and pedobarometric variables as well classifying the type of disorder arch longitudinal arch of the foot. 3/Qualitative analysis of the arch, based on plantography results and the Arch Index, shows inconsistency in results obtained with different methods. 4/The obtained results show further necessity to conduct more studies to develop methods of standardization of foot arch assessment.

Keywords: Foot arch, dynamometric measurements, footprints

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Flat feet are complex deformities common among children and adults [4]. Clinically, flat foot is a foot with not present or excessively fallen medial longitudinal arch [2]. According to Arukanul, the symptoms also include abduction of the lower ankle joints and valgus position of the calcaneus [3]. Correct arch of the foot is important, both for keeping a stable upright posture, locomotion and ensuring proper quality of life [4]. Adequate flat foot diagnostics requires modern and repeatable methods of assessment of foot construction and function, based on strictly defined, reliable and repeatable measurement and classification techniques. In clinical practice, the probability of right diagnosis and, as a result, of making right prognostic and clinical decisions is crucial [5]. This refers to the whole set of foot arch diagnostic tests that are modified through different examiners, as well as different methods of assessment of lesions or absence of pes planus. Morphology and pathology examinations use common, simple methods based on footprint, or plantograph, analysis. Schwartz was one of the first scientists who identified a series of parameters on the basis of a footprint [6]. Since then, a wide range of foot morphology and pathology assessment methods have been developed, based on classical plantographic analyses: hallux valgus index, arch index, Staheli arch index, Chipaux-Smirak index, Sztriter-Godunow Index, Clarke angle [7–10], methods of clinical analysis with the use of visual assessment [11,12], tests performed by means of measurement equipment [13,14], radiology [15,16] or more and more popular methods that use photographic analysis, pedobarographs or advanced biometrological devices [2,17–19]. One of the most frequently recalled methods of assessment of the longitudinal foot arch, based on plantographic footprint is the method developed by Cavanagh and Rodgers – the Arch Index AI [20]. In its classic version, patient’s footprint is made on calibrated paper, with the patient standing in an upright, relaxed position. The footprint is then divided into three equal sections (without toes) and the longitudinal arch index is calculated based on the analysis of the footprint surface area, according to the following formula:

$$\text{AI} = \frac{B}{A} + B + C. $$

However, such analysis is quite tedious and time-consuming. It also depends on the examiner and creates a great risk of measurement errors. The method of calculating the Arch Index is presented in Fig. 1.

1.1. Objective

The paper sets out to development and verification of own, automated diagnostic algorithm for evaluation of the longitudinal arch of the foot with the use of the Zebris FDM-S dynamometric platform. It
Table 1
Age and anthropometric variables of the sample

<table>
<thead>
<tr>
<th>Feature</th>
<th>Average X</th>
<th>Standard dev. SD</th>
<th>Coeff. of variation V%</th>
<th>Min-max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>26.2</td>
<td>6.89</td>
<td>22.8</td>
<td>17–34</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>182.7</td>
<td>8.73</td>
<td>4.5</td>
<td>156–196</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>83.5</td>
<td>14.08</td>
<td>17.7</td>
<td>52.9–111</td>
</tr>
</tbody>
</table>

describes foot arch assessment based on the AI calculated on the basis of discretized measurements of distribution of forces on the ground, by means of Zebris platform and compares the results with standard footprints indexes.

2. Methods

The examination was conducted as part of a bigger project held in September 2017 in Katowice, during international volleyball competition for people with intellectual disabilities. The research sample consisted of 26 players and their carers, aged 17–34 (x = 26.2). Using Zebris platform the distributions of the ground reactions were measured. The next step of the data processing was transformation of the measured data to Matlab software. Based on distribution of ground reaction on each frame AI indexes were calculated for whole group of participants. The result was averaged for each person and for each test. In the last step the values of AI indexes were compared to each other, to Clarke angle indexes and to Sztriter-Godunow indexes.

The statistical analysis of the collected material was carried out using the MedCalc ver.18.2.1 statistical package. After conducting the study of the distribution of variables using the Kolmogorov-Smirnov test, a standard describing analysis was performed using mean values, standard deviations, coefficients of variation. The correlation coefficient of the Pearson’s straight line was used to assess the relationship between the foot arching results. The assessment of the variation between the types of arched longitudinal arch arches was carried out using the Chi2 test.

Sample characteristics are presented in Table 1.

Regarding age and basic anthropometric data (body weight and height), the examined group was homogeneous, with normal distribution of the analyzed variables and a small scattering of individual measurements, which is shown by standard deviations and coefficients of variation.

3. Results

The examination involved two stages. First, classic plantography indexes that describe the longitudinal arch of the foot were measured: Clarke angle, Sztriter-Godunow index (KY). The measurements were conducted by means of digital podoscope produced by OPIW company (Opolskie Przedsiębiorstwo Innowacyjno-Wdrożeńiowe).

Then, the examined persons stood on a platform measuring distribution of plantar pressure values. The patients stood still for 30 seconds while the measurements were taken. The results were exported to text files and uploaded to Matlab program. In order to assess the foot arch, an automated algorithm was developed according to the algorithm described by Menz et al. [22]. For each examined individual, AI values for the left and right foot were calculated.

The characteristics of the selected variables describing the foot arch are presented in Table 2.
Table 2

<table>
<thead>
<tr>
<th>Examined variable</th>
<th>Average X</th>
<th>Min-max</th>
<th>Standard dev. SD</th>
<th>Coeff. of variation</th>
<th>V%</th>
<th>K-S Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arch Index AI</td>
<td>0.27</td>
<td>0.09–0.39</td>
<td>0.08</td>
<td>29.04</td>
<td></td>
<td>p = 0.072</td>
</tr>
<tr>
<td>Clarke angle</td>
<td>40.6</td>
<td>20.7</td>
<td>6.83</td>
<td>16.82</td>
<td></td>
<td>p = 0.553</td>
</tr>
<tr>
<td>Sztriter-Godunow index KY</td>
<td>0.41</td>
<td>0.17–0.61</td>
<td>0.09</td>
<td>23.25</td>
<td></td>
<td>p &gt; 0.10</td>
</tr>
</tbody>
</table>

Fig. 2. Digital footprint analysis with OPIW digital podoscope and method of calculating selected values of the longitudinal arch, Clarke Index, Sztriter-Godunow KY Index [6,8,18].

Fig. 3. Point chart of Pearson correlation between Arch Index and Clarke angle.

Values of the variables obtained from statistical analysis, describing the longitudinal foot arches had normal distribution and individual results were not very diversified. The results were manually plotted as for the Clark angle and average as for the Sztriter-Godunow index (KY) and the Arch Index (Table 2).

To investigate relations between the values of certain indexes, the linear correlation between the studied coefficients was determined by means of Pearson’s correlation. Results of the analyses are presented in the point Charts 3 and 4.

The analysis revealed a high correlation between the Clark angle and the Arch Index \( r = -0.515 \) and a very high correlation between the Arch Index and the Sztriter-Godunow index \( r = 0.704 \).

The next step involved a comparison of the results of the longitudinal foot arch examination with the classification criteria applied in certain methods of assessment of the longitudinal arch of the foot, as described in the subject matter literature [7,8,22].
Table 3

<table>
<thead>
<tr>
<th>Foot arch</th>
<th>Arch Index</th>
<th>Clarke angle</th>
<th>Sztriter-Godunow Index KY</th>
</tr>
</thead>
<tbody>
<tr>
<td>High arch</td>
<td>&lt; 0.21</td>
<td>&gt; 54</td>
<td>&lt; 0.25</td>
</tr>
<tr>
<td>Normal arch</td>
<td>0.21–0.28</td>
<td>42–54</td>
<td>0.26–0.45</td>
</tr>
<tr>
<td>Low arch</td>
<td>&gt; 0.28</td>
<td>&lt; 41</td>
<td>&gt; 0.46</td>
</tr>
</tbody>
</table>

Fig. 4. Point chart of Pearson correlation between Arch Index and Sztriter-Godunow Index.

Fig. 5. Occurrence of foot types according to Arch Index (AI) classification.

Figures 5–7 show the results of comparative analysis of the types of the foot arches identified on the basis of the presented criteria.

The assessment of frequency of foot types shows significant discrepancies depending on the adopted criteria. The analysis of frequency of certain foot types, using the Chi-square test, confirms this differentiation and points out statistically relevant differences in occurrence of foot types measured with different assessment methods (Table 4).
<table>
<thead>
<tr>
<th>Table 4</th>
<th>Different types of foot arches according to criteria applied in different assessment methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chi-square test Clarke angle    Sztriter-Godunow Index KY</td>
<td></td>
</tr>
<tr>
<td>Arch Index       $p = 0.0251$                $p = 0.0012$</td>
<td></td>
</tr>
<tr>
<td>Clarke angle     $p = 0.0007$</td>
<td></td>
</tr>
</tbody>
</table>

$p < 0.05$ significant statistical differences in occurrence in the compared groups.

Fig. 6. Occurrence of foot types according to classification based on Clarke angle.

Fig. 7. Occurrence of foot types according to Sztriter-Godunow (KY) classification.

4. Discussion

Static foot assessment is one of the commonly used methods to get information and make clinical decisions in order to identify possible etiological factors of the lower extremities dysfunctions or injuries. It serves as a basis to plan and administer therapeutic interventions. Most of the commonly applied indexes that describe the longitudinal foot arch are calculated from footprints. However, results of this traditional measurement method and clinical measurements, depend on examiner’s experience, which often leads
to a low reliability and repeatability [21]. Some authors describe inconsistency between various procedures of assessment of the longitudinal foot arch, and point out that these differences occur already in footprints made by means of different measurement techniques. The analysis of our investigation leads to similar conclusions. Different measuring instruments used to measure foot anthropometric variables often determine inconsistency of obtained results. Therefore, this needs to be taken into account when different measuring methods are applied, as well as when measurements are performed with different loads applied to the feet [18,23,24]. Digitization or electronic pedography procedures reduce differences in measurements but do not eliminate them completely. When it comes to assessment with the Arch Index, many researchers try to find solution based on different techniques, wishing to automate measurements and limit the risk of measurement errors. According to Menz et al., Arch Index is a very good tool and classification categories based on it are almost perfect. Menz also emphasizes the reliability of tests performed by one and many examiners [22,25]. However, he also points out the necessity of measurement digitization and the use of computer analysis as a “gold standard” [25]. According to many authors, Arch Index is strongly associated with other measurement methods: navicular height [22], radiography of the foot arches [26], midfoot pressure [10], hindfoot position and mobility [27]. Arch Index examinations also use visual measurement methods based on the 2D/3D technology [19], measurements with classic flat rubber pads and Otsu thresholding [17]. Studies of correlations between the Arch Index values obtained by means of Zebris podobarometric platform show a high linear correlation between the AI and Clark angle, and Sztriter-Godunow index. The algorithms of Arch Index measurement on a stabilographic platform provide a unique opportunity for simultaneous stabilometric measurements, load distribution analysis and calculation of the arch index. This allows to gain more detailed information about mutual correlations between foot anthropometric parameters, surface area analysis, the plantar pressure and balance mechanisms. This way, the diagnostic risk is reduced. Higher diagnostic adequacy can be obtained by complementing arch examination on podobarometric platform with the analysis of hindfoot position [28]. And while authors’ own research show high correlation with the results of classic plantography examination, criteria for classifying the types of foot arches raise doubts. Own research confirmed observations found in the subject literature, about the inconsistency between types of feet, identified with different methods [21,23]. Thus, it is worth to consider whether the thitherto classification criteria are still relevant. It seems reasonable to develop clear qualification criteria based on examinations in large groups. They must be based on objective diagnostic criteria and automated diagnostic methods, that would be independent of examiner’s subjective assessment. An extended analyses should follow, together with the development and application of a “gold standard” in the assessment of the foot arch, and evaluation of repeatability of examinations, both in case of one or more examiners.

5. Conclusions

1. Examination confirmed strong linear correlation between the Arch Index results obtained during examinations on a stabilometric platform and plantography examination.
2. The proposed algorithm for AI evaluation using the Zebris FDM-S dynamometric platform enables simultaneous analysis of stabilometric and pedobarometric variables as well classifying the type of disorder arch longitudinal arch of the foot.
3. Qualitative analysis of the arch, based on plantography results and the Arch Index, shows inconsistency in results obtained with different methods.
4. The obtained results show further necessity to conduct more studies to develop methods of standardization of foot arch assessment.
Conflict of interest

None to report.

References


