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Review article

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# The effects of hallux valgus and hallux rigidus surgery on gait biomechanics: a systematic review

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

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## Abstract

Hallux valgus (HV) and hallux rigidus (HR) are common foot conditions that lead to deterioration of health status. This review aims to summarize and update information on the currently published research explicitly related to the influence of HV and HR surgeries on lower extremity gait biomechanics.

A review of papers published from 1999 to 2020 has been conducted. The databases searched included Science Direct, PubMed Central, PubMed and EBSCO.

After HV surgeries, most of patients' spatio-temporal parameters remain the same as they were before them. Changes in plantar pressure parameters of the hallux region are inconclusive and depend on a study. In patients after HR surgeries, such as cheilectomy and Ist metatarsophalangeal joint (MTP I) arthrodesis, they do not affect knee or hip kinematics. The influence of MTP I arthrodesis on ankle joint kinematics is unclear. Cheilectomy in most cases increases MTP I motion in the sagittal plane. The HV angle and the intermetatarsal angle have significantly decreased after surgeries in all papers. American Orthopedic Foot and Ankle Society MTP–IP score results are also much better than their pre-operative values in patients after HV and HR surgeries.

Surgical treatment decreases pain and allows patients to perform activities of daily living, but it does not normalize gait parameters. Further research on a large group of patients is needed to comprehensively assess kinetic, kinematic and plantar pressure parameters as well as muscle activity after HV and HR surgeries.

**Keywords: biomechanics, gait, hallux rigidus, hallux valgus**

## Introduction

Human gait is the basic activity, the disturbance of which results in a lack of comfort, inability to perform activities of daily living, which may result in a certain exclusion from social life. Therefore, it is very important to return to normal functioning and correct locomotion after any type of surgery. Hallux valgus (HV) and hallux rigidus (HR) are two common pathologies that affect the first metatarsophalangeal joint (MTP I). Both conditions can impact the joint to such an extent that corrective surgery may be required. HV is one of the most common forefoot conditions. It occurs when the first metatarsal bone shifts medially and the great toe deviates laterally. The etiology of HV deformity is complex and is usually associated with familial history, hypermobility, tight and/or high-heeled shoes and obesity [1,2]. The epidemiologic data vary depending on their source – it is believed that the problem afflicts 2–4% of the population [1]. According to Hecht & Lin [2] women are diagnosed up to 15 times more often than men. The radiographic severity of HV is based on hallux valgus angle (HVA) and intermetatarsal angle (IMA). Another tool allowing assessment of foot and ankle conditions is the American Orthopedic Foot and Ankle Society Score (AOFAS), which has been shown to be reliable, valid and representative in clinical use [3].

HR it is arthritis of the MTP I and is associated with limitation of range of motion and pain. The etiology of HR is still unclear [4]. HR can be caused by MTP I injury or repetitive micro-injuries. It may also be associated with first metatarsal head (MTH) shape, metatarsus primus elevatus, short or long I metatarsal bone and tight Achilles tendon [5].The prevalence of HR is estimated at 2.5% in patients over 50 years in the US and up to 79% of them have bilateral involvement [6]. Higher prevalence is noted by Anderson, Ho, & Baumhauer [7]. They report that nearly 10% of the population have symptomatic HR and that its prevalence is higher in older patients, 20–48% among people above 40 years.

The analysis of publications [8,9] describing biomechanics of gait in people with HR and HV shows unfavorable changes in gait parameters. In patients with HR gait is significantly altered in foot and ankle regions such as hallux, forefoot, hindfoot and tibia [9]. Range of motion in MTP I in the sagittal plane is observed to significantly decrease in all gait cycle phases [9] among patients with HR. Hallux dorsiflexion, hallux plantar flexion and hindfoot dorsiflexion are reduced [6]. HV deformity also affects gait biomechanics. It decreases gait speed, cadence, toe-off pitch angle, peak swing speed, MTP I sagittal plane movement, lengthens foot-flat phase, increases total contact duration at hindfoot, weakens push-off and peak vertical force at the first toe [10]. In patients with HV there is usually observed higher plantar pressure under second and third MTH, fourth and fifth toes. At the same time plantar pressure under hallux is decreased [11], but not always spatio-temporal parameters are altered [8,11]. Whereas the above discussed operations are frequently performed to reduce pain and improve the quality of life of patients, it is worth emphasizing the fact that there are not many studies that describe how people's gait changes after such interventions. According to our knowledge one review article was performed in the topic of gait parameters after HV surgeries, it included only four articles [12].Therefore, the purpose of this study was to review papers investigating kinematic and kinetic parameters during walking in patients after HV or HR surgeries to help improve understanding of how those surgeries influence gait biomechanics.

## Material and methods

### Search strategy

During the preparation of the article, the PRISMA guidelines were followed. The review was limited to articles analyzing gait biomechanics in patients with hallux valgus (HV) or hallux rigidus (HR) deformity. The electronic search of databases was performed on 19th March 2020. The articles were limited to those published from January 1999 to March 2020. The Science Direct, PubMed Central, PubMed and EBSCO databases were searched to identify appropriate literature using the following key: gait analysis AND (hallux limitus OR hallux rigidus OR hallux valgus) AND surgery.

### Eligibility

Only full-text articles were selected from the electronic databases. Titles, abstracts and full texts of the retrieved documents were sequentially reviewed by K.L and M.B to determine their relevance to the topic. Also, the reference lists of all the studies included for review were searched manually for additional studies of relevance. The inclusion criteria were: 1) full text of the publication in English; 2) assessing gait kinetic or kinematic parameters and other parameters relating to gait; 3) analyzed gait after HV or HR surgery. Exclusion criteria included: 1) number of participants below 5; 2) arthroplasty surgical methods; 3) participants with other significant health problems than HR or HV; 4) no corrective surgery of HV or HR among participants, 5) conference abstracts and review papers were excluded, 6) articles in which only comparison of surgical methods was made were excluded.

### Review process

The duplicate articles from different databases were rejected. The title and abstract of the selected articles were first screened according to the eligibility criteria. Furthermore, full-text evaluation was performed if the title and abstract could not provide adequate information for the article screening process. The rejected articles were re-screened to avoid misinterpretation. The titles, abstracts and full text of the papers identified by the search were subsequently screened by two independent reviewers (the authors: K.L. and P.K.) to choose those that met the selection criteria and to extract data. Decisions about which trials should be selected were made by negotiation. The reference lists of all the studies included for review were searched manually for additional studies of relevance by one author (K.L.). One reviewer (K.L.) compiled all the articles using a reference manager software (Mendeley Ltd., USA). Next, the selected and accepted articles were divided into three subgroupsevaluating:1) kinematic, 2) kinetic parameters, 3) plantar pressure, and 4) scales.

Data extraction was performed by two reviewers independently (K.L. and P.K.) and then agreed. Type of intervention; purpose of the study; study group characteristics, test conditions, equipment; results were extracted.

**Quality assessment**

Methodological quality of the trials selected for this review was then evaluated using a checklist for both randomized and non-randomized studies [13]. The checklist consisted of 27 items divided into five sub-scales: (1) Reporting (10 items) – which assessed whether the information provided in the paper was sufficient to allow the reader to make an unbiased assessment of the findings of the study; (2) External validity (3 items) – which addressed the extent to which the findings from the study could be generalized to the population that the study subjects were derived from; (3) Internal validity – bias (7 items) – which addressed bias in the measurement of the intervention and the outcome; (4) Internal validity – confounding (6 items) – which addressed bias in the selection of study subjects; (5) Power (1 item) – which attempted to verify whether the negative findings from a study could be due to chance. The assessment of the first three criteria has been used in this paper, therefore questions concerning only these sections are presented below. Reporting the checklist comprised the following questions: 1. Is the hypothesis/aim/objective of the study clearly described?; 2. Should the main outcomes be measured and clearly described in the Introduction or Methods section?; 3. Are the characteristics of the patients included in the study clearly described?; 4. Are the interventions of interest clearly described?; 5. Are the descriptions of principal confounders in each group of subjects clear?; 6. Are the main findings of the study clearly described?; 7. Does the study provide estimates of random variability in the data for the main outcomes?; 8. Have all the important adverse events that may result from the intervention been reported?; 9. Have the characteristics of patients lost to follow-up been described?; 10. Have actual probability values for the main outcomes (e.g. 0.035 rather than <0.05), except where the probability value is less than 0.00, been reported? External validity checklist included;11. Were the subjects asked to participate in the study representative of the entire population from which they were recruited?; 12. Were those subjects who were prepared to participate representative of the entire population from which they were recruited?; 13. Were the staff, places, and facilities where the patients were treated, representative of the treatment the majority of patients receive? Internal validity – bias checklist included; 14. Was an attempt made to blind study subjects to the intervention they had received ?; 15. Was an attempt made to blind those measuring the main outcomes of the intervention?; 16. If any of the results of the study were based on "data dredging", was that made clear?; 17. In trials and cohort studies, do the analyses adjust for different lengths of patients' follow-up , or in case-control studies, is the time period between the intervention and the outcome the same for cases and controls?; 18. Were the statistical tests used to assess the main outcomes appropriate?; 19. Was compliance with the intervention/s reliable?; 20. Were the main outcome measures used accurate (valid and reliable)?

We have resigned from using Internal validity – confounding and Power assessment sections due to a large number of questions not applicable to the articles included in our review. The answers were scored 0 or 1, except item number 5 which scored 0 to 2. Questions 1–10 were scored 1 if the answer was "yes" or 0 if the answer was "no". Questions 11–20 were scored 1 if the answer was "yes" or 0 if the answer was "no" or "unable to determine". The maximum number of points in each section was as follows: Reporting – 10, External validity – 3 and Internal validity – bias – 7. Therefore, the total maximum score was 21 points.

## Results

Sixteen articles were selected for the review, following the eligibility criterion of full-text studies (Fig. 1). Initially, the electronic database screening process yielded 805 articles. The screening of the titles and abstracts enabled to single out 32 articles, which were identified to be related to the aim of the literature survey. No articles were retrieved from the reference lists.

**Quality assessment**

All the papers considered for analysis were rated (11–15/21 points)using Downs and Black Quality Assessment Tool [13] (Table 1). The lower rating was mainly due to the External validity section, where most of the papers (9 papers) had 0 or 1 point (6 papers).

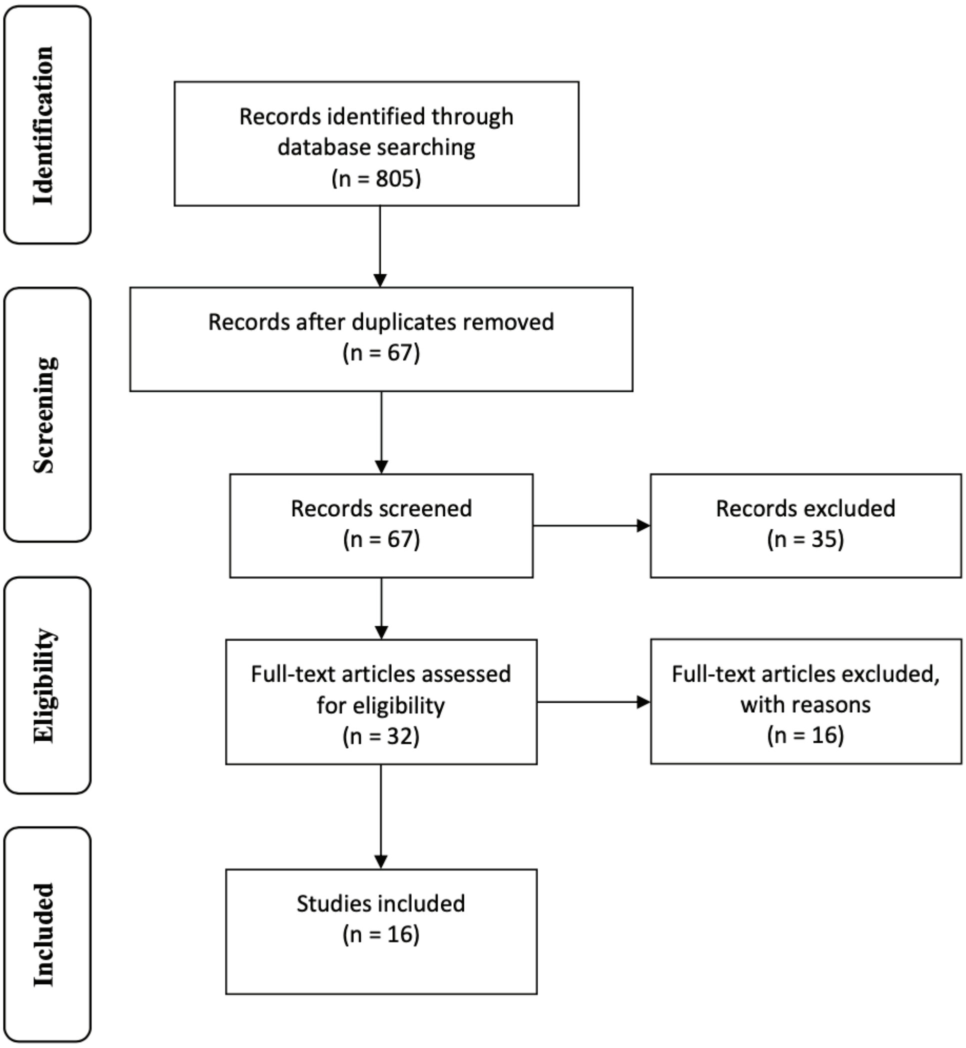


**Fig. 1.** Flowchart demonstrating the selection of articles through the review process

Only one article [14] was rated at the maximum number of points.

In the Reporting section, all the papers were rated 6–8/11 points. The scores were affected by negative answers to questions 5 (Are the descriptions of principal confounders in each group of subjects clear?) and 8 (Have all the important adverse events that may result from the intervention been reported?) in all of the cases. Only one article [18]was rated the lowest 6/11 points. In that case, a negative answer to question 4 (Are the interventions of interest clearly described?) had an impact. In the Internal validity – bias section all the papers were rated 4-5/7 points. The scores were mainly affected by negative answers to questions 14 (Was an attempt made to blind study subjects to the intervention they had received?) and 15 (Was an attempt made to blind those measuring the main outcomes of the intervention?) in all of the cases. Summarizing, Overall Quality Index Score ranged from 48% to 71%. Quality assessment revealed a problem with external validity in most of the papers, e.g. the participant groups were not representative for the population and some aspects of internal validity.

The subsections that follow contain analysis of kinematic, kinetic and plantar pressure parameters as well as different patient assessment tools such as AOFAS score, which are referred to separately as scales for HV and HR. There are no articles concerning kinetic parameters for HV because none of them met the inclusion criteria.

**Kinematic parameters for Hallux Valgus**

Kinematics parameters during walking after HV surgery were described in five papers [15–19] (Tab. 2).

**Tab. 1.** Quality assessment scores of included studies

| Question | Canseco *et al.*, 2012 [15] | Sadra *et al.*, 2013 [16] | Chopra, Moerenhout and Crevoisier, 2016 [17] | Klugarova *et al.*, 2016 [18] | Moerenhout, Chopra and Crevoisier, 2019 [19] | Defrino *et al.*, 2002 [20] | Brodsky *et al.*, 2007 [21] | Nawoczenski, Ketz and Baumhauer, 2008 [22] | Canseco *et al.*, 2009b [23] | Smith *et al.*, 2012 [24] | Kuni *et al.*, 2014 [25] | Stevens *et al.*, 2016 [26] | Martínez-Nova *et al.*, 2008 [27] | Schuh *et al.*, 2009 [28] | Schuh *et al.*, 2010 [29] | Martinez-Nova *et al.*, 2011 [14] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reporting (questions: 1–10) | | | | | | | | | | | | | | | | |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 7 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 11 | 1 | 1 | 1 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 |
| 10 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Sum | 7/11 | 7/11 | 7/11 | 6/11 | 8/11 | 8/11 | 8/11 | 7/11 | 8/11 | 7/11 | 8/11 | 7/11 | 8/11 | 8/11 | 8/11 | 7/11 |
| External validity (questions: 11–13) | | | | | | | | | | | | | | | | |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 13 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 |
| Sum | 0/3 | 1/3 | 0/3 | 0/3 | 0/3 | 0/3 | 1/3 | 0/3 | 0/3 | 0/3 | 1/3 | 1/3 | 0/3 | 1/3 | 1/3 | 3/3 |
| Internal validity – bias (questions: 14–20) | | | | | | | | | | | | | | | | |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 17 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| 18 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 19 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 20 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Sum | 4/7 | 4/7 | 4/7 | 4/7 | 4/7 | 4/7 | 4/7 | 4/7 | 4/7 | 4/7 | 4/7 | 4/7 | 5/7 | 5/7 | 5/7 | 5/7 |
| Total | 11/21 | 13/21 | 11/21 | 10/21 | 12/21 | 12/21 | 13/21 | 11/21 | 12/21 | 11/21 | 13/21 | 12/21 | 13/21 | 14/21 | 14/21 | 15/21 |

**Tab. 2.** Data extraction from reviewed articles for HV kinematic parameters

| Study | Intervention | Purpose of the study | Study group/age (years)<br>Test conditions/Equipment | Results |
|---|---|---|---|---|
| Canseco *et al.*, 2012 [15][Scale] | No information | Analyze changes in multi-segmental foot and ankle kinematics in patients after operative correction of HV. | 19 adults: 52.5 (24–72)<br><br>24 feet (15 lefts and 9 rights). Motion capture system. | Postoperative comparisons to the normal population showed that only walking speed and stride length were significantly smaller. |
| Sadra *et al.*, 2013 [16] | Scarf procedure | Does the corrective HV surgery improves gait and balance performance in an adult patient population? | 10 adults post-operative: (50 ± 9.4 years)<br>19 adults pre-operative: (44.3 ± 11.9)<br>11 control participants: (22.9 ± 1.9)<br><br>Sensor technology (LEGSys; BioSensics)<br><br>Evaluation: Preoperative 10 ± 2.3 weeks post-operative. | No significant difference in step length and support time.<br><br>No difference in walking speed between pre-operative group and a control group. Significant reduction in walking speed compared to preoperative and control group. |
| Chopra, Moerenhout and Crevoisier, 2016 [17][PP] | Modified Lapidus procedure | Assessment of the outcome of modified Lapidus at 6 months postoperatively, using gait assessment method to determine if the specified gait parameters effectively relate to the clinical scores and the radiological results. | 10 females: (51.3 ± 10.3) with moderate to severe HV deformity<br>Control group:11 healthy female volunteers (50.4 ± 7.1) with no sign of HV deformity.<br><br>Gait assessment was performed, once for controls and twice for the case group-preoperatively and 6 months post-operatively.<br><br>Pressure insoles, accelerometers and gyroscopes. | The postoperative versus preoperative comparison showed a significant difference in push-off duration and toe-off pitch angle.<br><br>Spatio-temporal parameters after surgery were significantly worse than in the control group.<br><br>MTP I: In the sagittal plane, ROM in both HV and post modified Lapidus groups was significantly reduced in comparison to the healthy controls. In the coronal plane, significantly reduced ROM was reported in HV group in comparison to controls. |

**Tab. 2.** cont.

| Study | Intervention | Purpose of the study | Study group/age (years)<br>Test conditions/Equipment | Results |
|---|---|---|---|---|
| Klugarova *et al.*, 2016 [18] | First metatarsal osteotomy | Compare spatiotemporal parameters, lower limb and pelvis kinematics during the gait cycle in patients with HV before and after surgery and in relation to a control group. | 17 females (51.5 ± 11.4) with clinical and x-ray diagnosed HV deformity<br>The postoperative gait analysis evaluation – 4 months postoperatively.<br>After the surgery, a gypsum fixation was used for 4–6 weeks, followed by physical therapy.<br><br>Motion capture system. | HV surgery resulted in significantly greater decrease in the walking speed and increase of step time.<br><br>HV surgery did not influence the lower limb kinematics.<br><br>The maximum of plantar flexion during toe off was significantly decreased. A smaller maximum of hip abduction with pelvis elevation at the beginning of the stance phase and a greater maximum of hip adduction with pelvis depression at the end of stance phase in the operated leg as compared to the non-operated leg were found.<br><br>In the non-operated leg after HV surgery. Significantly decreased cadence and walking speed. Step length of the non-operated leg became significantly shorter and took more time, which resulted in significantly increased duration of single support and double support phases. However, there were no significant changes in lower limb and pelvis kinematics on the non-operated leg after HV surgery. |
| Moerenhout, Chopra and Crevoisier, 2019 [19][PP, Scale] | Modified Lapidus procedure | Assessment the midterm outcome following modified Lapidus procedure by comparing the radio-clinical and gait outcomes at preoperative, 6 months and 12 months following surgery. | 10 female patients with signs of moderate to severe HV: (51.3 ± 8.2)<br><br>Pressure insoles, radiological, and gait assessment. | At 6 months follow up, the toe-off pitch angle showed significant deterioration from the preoperative status. At 12 months, load duration during the stance phase and heel strike pitch angle were found to have significantly increased compared to the pre-operative values.<br>Compared to the pre-operative outcome, significant reduction in motion was recorded at forefoot-shank motion in the coronal plane at 6 and 12 months follow – up. |

Plantar pressure (PP) – study in Tab. 5, Scale – study in Tab. 7.

**Tab. 3.** Data extraction from reviewed articles for HR kinematic parameters

| Study | Intervention | Purpose of the study | Study group/ age (years)<br>Test conditions/ Equipment | Results |
|---|---|---|---|---|
| Defrino *et al.*, 2002 [20][Kinet, PP, Scale] | MTP I arthrodesis | Quantify the effects of first metatarsophalangeal arthrodesis on gait and plantar pressures. | 4 women and 4 men with an average age of 56 [38-72].<br>Motion capture system, force platform.<br>3 trials were obtained both pre – and post-operatively for each patient. The mean time to follow-up was 34 months (26 – 44). | The patient's operated limb was found to have a significantly decreased step length when normalized for height.<br>There was no significant change in the hip or knee kinematics. |
| Brodsky *et al.*, 2007 [21] [Kinet, PP, Scale] | MTP I arthrodesis | Evaluate the effects of MTP I joint arthrodesis on gait. | 23 patients aged (58 ± 9.5) with symptomatic HR refractory to non-operative treatment were treated with first MTP joint arthrodesis.<br>Motion capture system, force plate.<br>Follow-up – 1.46 (1 – 2.9) years after surgery | Comparison pre – vs. post-operatively.<br>The kinematic analysis revealed no significant changes in sagittal ankle ROM.<br>A significant increase in single-limb time support was observed in the involved extremity pre – vs. post-operation.<br>A significant decrease was noted in step width from pre – vs. post-operation. |
| Nawoczenski, Ketz and Baumhauer, 2008 [22][PP, Scale] | Cheilectomy | Assessement *in vivo* dynamic first MTP joint kinematics and plantar pressures. | 20 patients (9 females, 11 males) aged (34 – 63) were prospectively evaluated prior to undergoing cheilectomy for grades I – III HR.<br>Eleven subjects were surveyed at 6 years. Plantar pressure data were acquisition. Dynamic pedobarograph.<br>Electromagnetic was used to track 3D position and orientation of the calcaneus, the first metatarsal and the hallux during quiet standing, active ROM during weightbearing and walking. | Significant increases pre – vs. post-operation in dorsiflexion and hallux abduction were found for active motion and during gait. |
| Canseco *et al.*, 2009b [23] [Scale] | Cheilectomy | Investigation the temporal and kinematic characteristics of segmental foot motion in a group of patients with HR before and after cheilectomy. | 19 subjects (11 males, 8 females) 50.5 (34– 75). All subjects demonstrated mild to moderate HR.<br>Motion capture system – Milwaukee Foot Model.<br>Pre-operative evaluation was done at an average of 33 days prior to surgery. Post-operative evaluation was done at an average of 1.5 years after surgery. Post – operative testing was conducted only after complete clinical return to a stable ambulatory pattern. | Post-cheilectomy, walking speed, cadence, and stride length significantly increased, stance duration was significantly shortened as compared to the preoperative.<br>A comparison of patients with HR to healthy ambulators showed that the pre-op group had significantly longer stance duration.<br>After surgery, MTP I ROM remained significantly decreased in load response and initial swing, but improved during the rest of the gait phases.<br>MTP I ROM was not significantly different postoperatively in the coronal or transverse planes.<br>Postoperatively, hallux sagittal position improved towards normal, reaching significant levels from initial swing to mid-swing.<br>No significant differences in hallux segment positions were found in the coronal or transverse planes before or after surgery. |

**Tab. 3.** cont.

| Study | Intervention | Purpose of the study | Study group/ age (years)<br>Test conditions/ Equipment | Results |
|---|---|---|---|---|
| Smith *et al.*, 2012 [24][Kinet, Scale] | First MTP cheilectomy. The cheilectomy did not resect the dorsal third of the MTH, rather the head was resected no more than to the level of the dorsal cortex of the metatarsal shaft | Testing the hypothesis that cheilectomy for HR improves gait by increasing ankle push-off power. | 17 (8 women, 9 men), aged: 47.4 (37 – 64).<br>Motion capture system, force plate.<br><br>Gait analysis was performed within 4 weeks prior to surgery and then repeated at least 1 year after surgery.<br><br>The average follow-up was (1.8 ± 0.9) (1.02 – 3.58) years. | There were no significant changes in either velocity or sagittal plane ankle ROM.<br><br>First MTP passive motion significantly increased post-operation. |
| Kuni *et al.*, 2014 [25][Scale] | Cheilectomy | Investigation the kinematic characteristics of multi-segmental foot motion in patients with HR before and after cheilectomy both when walking on level ground as well as on stairs. | 8 patients (6 women, 2 men) aged: (59.1 ± 6.4).<br>At least 6 stair ascents and descents on a custom-made 80-cm-wide staircase which consisted of 5 steps of 15 cm in height and a step distance of 32 cm.<br><br>Motion capture system.<br><br>Postoperative evaluation was done at (1.1 ± 0.3) years after the operation. | The hallux dorsi/plantarflexion ROM was significantly lower than in controls in level walking and descending stairs pre – and postoperatively.<br><br>In the comparison between preoperative and postoperative state, the hallux dorsi/plantarflexion ROM significantly decreased by 2.5 deg in level walking.<br><br>The analysis of level gait sub-phases showed only postoperatively significant differences between patients and controls for the maximum hallux dorsiflexion in pre-swing – controls: (38.2± 5.8) deg; patients preoperatively: (29.6± 6.0) deg.<br>Pre – and postoperative walking speeds matched in the patient group in level walking and in walking up the stairs.<br>Postoperatively, patients significantly reduced their speed when walking down the stairs as compared to the preoperative speed. |

**Tab. 3.** cont.

| Study | Intervention | Purpose of the study | Study group/ age (years)<br>Test conditions/ Equipment | Results |
|---|---|---|---|---|
| Stevens *et al.*, 2016 [26]PP, Scale | MTP I arthrodesis | Checking where the foot compensates for the loss of motion after an MTP1 arthrodesis in order to restore the gait pattern toward a normal gait pattern. | 8 patients (59.4 ± 8.3): 6 underwent a unilateral MTP1 arthrodesis, 2 a bilateral MTP1 arthrodesis. Total of 10 feet with MTP1 arthrodesis.<br><br>12 healthy subjects (43.1±18.2): 9 were measured bilaterally, 3 unilaterally.<br><br>Total of 21 feet without arthrodesis.<br>Force plate, motion capture system.<br><br>Gait analysis took place at a median follow-up of 27 months (range: 18-60 months) postoperatively. | Step width was significantly smaller in the MTP I arthrodesis group compared to the healthy controls.<br><br>The MTP I arthrodesis group showed a significantly increased ROM in the terminal stance phase in the transverse plane in the hindfoot-tibia segment, which was the result of a more internally rotated hindfoot.<br><br>A significantly decreased ROM was observed after a MTP I arthrodesis in the frontal plane during midstance in the hindfoot-tibia segment, due to diminished eversion of the hindfoot.<br><br>Evaluation of motion patterns of the segments of interest and proximal joints showed no major differences between unilateral and bilateral treated patients.<br><br>Transverse plane motion showed a significantly reduced ROM after a MTP I arthrodesis in the forefoot-hindfoot segment during pre-swing, due to diminished adduction of the forefoot in this phase. In addition, significantly smaller plantarflexion was observed during midstance and terminal stance in this segment, which resulted in a significantly reduced ROM in the sagittal plane in the MTP I arthrodesis group. A significant increase in ROM after a MTP I arthrodesis, as a result of increased supination of the forefoot, was detected in the frontal plane during pre-swing in the forefoot-hindfoot segment.<br><br>Significantly decreased ROM of the hallux was observed in the loading response and terminal stance phase in the MTP I arthrodesis group, which was the result of less plantarflexion of the hallux during loading response and less dorsiflexion of the hallux during terminal stance. |

Kinetic parameters (Kinet) – study in Table 4., Plantar pressure (PP) – study in Table 6., Scale – study in Tab. 7.

In one of the analyzed studies [15], the type of operation was not specified. In two works: [17,19] – Lapidus procedure was performed, and in two papers [16,18] first ray osteotomy was carried out. In two papers [15,18] motion capture systems were used. On average, 14 patients were analyzed in the above studies, with the maximum number of 19. Most of the spatio-temporal parameters remained the same as before the surgery, except for the push-off duration and toe-off pitch angle in one study [17]. The temporo-spatial parameters were significantly worse than in the control groups [17]. After Scarf surgery the only one reduced parameter was the gait speed [16].

**Kinematic parameters for Hallux Rigidus**

Kinematic parameters during walking after HR surgery were described in seven papers (Tab. 3). In three of those articles plantar pressure parameters were characterized additionally, in three authors assessed kinetic parameters, and in all of them scales were used to evaluate patient's progress.

Cheilectomy was performed in three articles [22–24] and MTP I arthrodesis also in three [20,21,26]. In five papers motion analysis systems were used [20,22–24,26]. In papers where cheilectomy was done, the average number of subjects was 15.66, whereas in papers where arthrodesis was used it was 13. Cheilectomy and MTP I arthrodesis do not influence knee or hip kinematics [20]. The influence of MTP I arthrodesis on ankle joint kinematics is unclear [21,26]. Cheilectomy in most cases increases MTP I motion in the sagittal plane [22,23].

**Kinetic parameters for Hallux Rigidus**

Kinetic parameters during walking after HR surgery were described in 3 papers (Tab. 4). In one of those articles plantar pressure parameters were characterized additionally, in three authors assessed kinematic parameters (Tab. 2) and in all of them scales were used. Both arthrodesis and MTP I cheilectomy favorably influence ankle push-off power [21,24].

**Plantar pressure parameters for Hallux Valgus**

Plantar pressure parameters after HV surgeries were assessed in six articles (Tab. 5). Percutaneous distal soft tissue release (DSTR)-Akin procedures were carried out in two of them, in two others first ray osteotomies were performed, and in another two modified Lapidus procedure was used.

In four articles [14,17,19,27] there were insole pressure systems used and in one it was platform measurement systems [28,29]. The average number of patients in plantar pressure studies was 30.66, with the minimum of 10 and the maximum of 79. In osteotomy studies, plantar pressure under hallux and force time integral significantly increased [28,29]. Changes of plantar pressure parameters in the hallux region are inconclusive and depend on the study.

**Plantar pressure parameters for Hallux Rigidus**

Plantar pressure parameters after HR surgeries were assessed only in three articles (Tab. 6). Defrino et al. and Nawoczenski et al. [20,22] compared pre – and postoperative results, whereas Stevens et al. [26] compared post-operative results with the control group.

**Tab. 4.** Data extraction from reviewed articles for HR kinetic parameters

| Study | Intervention | Results |
|---|---|---|
| Defrino *et al.*, 2002 [20] Kinem, PP, Scale, * | MTP I arthrodesis | In evaluation of the ankle kinetics in the sagittal plane, a reduction in both plantar flexor torque and power during toe-off as compared to the non-operative and the healthy control limbs was found.<br>Comparison to the patient's normal limb and the healthy control showed that there were no significant differences in knee and hip kinetics. |
| Brodsky *et al.*, 2007 [21] Kinem, Scale, * | MTP I arthrodesis | The kinetic analysis of gait parameters indicated a significant increase in maximal ankle push-off power. |
| Smith *et al.*, 2012 [24] Kinem, Scale, * | MTP I cheilectomy | A significant difference was found between pre – and postoperative peak sagittal plane ankle push-off power. The peak sagittal plane ankle push-off power significantly increased post-op. |

Kinematic parameters (Kinem) – study in Table 3., Plantar pressure (PP) – study in Tab. 6., Scale – study in Tab. 7. *Purpose of the study, study group, test conditions/ equipment are in Tab. 3.

**Tab. 5.** Data extraction from reviewed articles for HV plantar pressure variable

| Study | Intervention | Purpose of the study | Study group/ age (years)<br>Test conditions/ Equipment | Results |
|---|---|---|---|---|
| Martínez-Nova *et al.*, 2008 [27] Scale | Percutaneous distal soft tissue release (DSTR)-Akin procedure. | Describing the effects of the percutaneous DSTR-Akin procedure on plantar pressure distribution, clinical outcome, and radiographic parameters measured at a minimum of 12 months postoperatively. | 26 women (16 right and 14 left).<br>All participants used the appropriate size of the same brand of shoes, pressure insoles.<br>To analyze the pressure distribution, the foot was divided by the software into 9 areas corresponding to heel, midfoot, first through fifth metatarsal heads, hallux, and lesser toes [second to fifth].<br>The average follow-up was 12.1 months. | Peak pressure in the hallux, decreased significantly.<br>Mean pressure in the hallux decreased significantly.<br>No significant changes were found for the other areas. |
| Schuh *et al.*, 2009 [28] Scale | 10 scarf osteotomy and20 Austin osteotomy | Illustrate the changes of plantar pressure distribution during the stance phase of gait in patients who underwent HV surgery and received a multimodal rehabilitation program. | 20 persons aged: (58.4 ± 13.8) underwent Austin and 10 patients – scarf osteotomy for correction of mild to moderate HV deformity.<br>Pressure platform. Areas of the great toe, second toe, first metatarsal head, and second metatarsal head, as well as the total foot were analysed.<br>AOFAS score and ROM of the first MTP joint were evaluated preoperatively and 6 months after surgery. Plantar pressure analyses were performed preoperatively and 4, 8 weeks, and 6 months after surgery. | The mean contact area in the greater toe between the preoperative examination and the assessment 6 months after surgery was statistically significant.<br>In the first metatarsal head region and the great toe region, there were an increase of maximum force and the force-time integral between the preoperative and 6-month assessments. |
| Schuh *et al.*, 2010 [29] Scale | Chevron osteotomy | Determine if a postoperative rehabilitation program helped to improve weightbearing of the first ray after chevron osteotomy for correction of HV deformity. | 29 patients with a mean age of 58 with mild to moderate HV deformity.<br>Pressure platform.<br>Preoperative and one-year postoperative plantar pressure distribution parameters including maximum force, contact area and force-time integral were evaluated.<br>Additionally, the AOFAS score, ROM of the first MTP joint and plain radiographs were assessed.<br>Areas of the great toe, second toe, first metatarsal head, and second metatarsal head, as well as the total foot were analyzed. | In the great toe, the mean maximum force increased1 year after surgery.<br>There was a significant increase in the mean contact area for the total foot and in the mean for the great toe region.<br>The mean force-time integral increased significantly at one-year follow-up for the great toe region. There was a significant increase of this parameter for the second metatarsal head region. |

**Tab. 5.** cont.

| Study | Intervention | Purpose of the study | Study group/ age (years)<br>Test conditions/ Equipment | Results |
|---|---|---|---|---|
| Schuh *et al.*, 2010 [29] Scale | Chevron osteotomy | Determine if a postoperative rehabilitation program helped to improve weightbearing of the first ray after chevron osteotomy for correction of HV deformity. | 29 patients with a mean age of 58 with mild to moderate HV deformity.<br>Pressure platform.<br>Preoperative and one-year postoperative plantar pressure distribution parameters including maximum force, contact area and force-time integral were evaluated.<br>Additionally, the AOFAS score, ROM of the first MTP joint and plain radiographs were assessed.<br>Areas of the great toe, second toe, first metatarsal head, and second metatarsal head, as well as the total foot were analyzed. | In the great toe, the mean maximum force increased1 year after surgery.<br>There was a significant increase in the mean contact area for the total foot and in the mean for the great toe region.<br>The mean force-time integral increased significantly at one-year follow-up for the great toe region. There was a significant increase of this parameter for the second metatarsal head region. |
| Martinez-Nova *et al.*, 2011 [14]Scale | Medial eminence of first MTH was removed, DSTR)-Akin procedure | 1. To elucidate whether a difference existed in the forefoot dynamic plantar pressure distribution after surgery [when compared with an age – matched healthy control group];<br>2. To establish which clinical, radiological, and anthropometric factors deter – mine the post-operative plantar pressures values. | 79 patients, aged: (54.7 ± 12.5) and 98 controls.<br>Plantar pressure insoles. All subjects had the same type of shoe.<br>The final clinical, plantar pressure, and radiographic examinations were done at a minimum follow-up of 2 years [mean: 28.1 months; range: 24–33 months] with no loss at follow-up. | No statistical difference post-operatively vs. pre-operatively in cadence and whole foot contact time.<br>Significant increase in the mean pressures the 4th, 5th MTHs and significant decrease for the hallux.<br>No significant differences were found between control group and the HV group. The post-operative plantar pressures showed significantly lower 4th and 5th MTH pressures in the controls than the post-operative values. No significant differences occurred in the hallux pressures. |
| Chopra, Moerenhout and Crevoisier, 2016 [17] Kinem, * | Modified Lapidus procedure | In maximum vertical force parameter for the preoperative versus postoperative comparison significant difference was reported only at the lateral toes – decrease and hallux regions – decrease.<br><br>In maximum peak pressure parameter for the preoperative versus postoperative comparison significant difference was seen in forefoot central – decrease and lateral toe regions – decrease.<br><br>Total contact duration was postoperatively: decreased in hallux, forefoot central regions and increased in hindfoot lateral, hindfoot medial, midfoot lateral, forefoot lateral regions. | | |
| Moerenhout, Chopra and Crevoisier, 2019 [19] Kinem, Scale, * | Modified Lapidus procedure | At 12 months follow-up, total contact time at hindfoot lateral was the only parameter reporting significant increase compared to the preoperative value. | | |

Abbreviations: Kinematic parameters (Kinem) – study in Tab. 2., Scale – study in Tab. 7. * Purpose of the study, study group, test conditions/ equipment are in Tab. 2.

**Tab. 6.** Data extraction from reviewed articles for HR plantar pressure variables

| Study | Intervention | Results |
|---|---|---|
| Defrino *et al.*, 2002 [20] Kinet, Scale, * | MTP I arthrodesis | None of the pedobarographic measurements in the MTH regions were different between preoperative and postoperative evaluations. The maximum force and peak pressure under the hallux significantly increased between the preoperative and postoperative evaluations. The contact area under the entire foot and under the hallux significantly increased between the preoperative and postoperative evaluations. |
| Nawoczenski, Ketz and Baumhauer, 2008 [22]Kinem, Scale, * | Cheilectomy | Four out of 15 patients showed increased lateral metatarsal loading preoperatively. Pressures shifted medially following surgery, but no significant changes were recorded. |
| Stevens *et al.*, 2016 [26]Scale, Kinem, * | MTP I arthrodesis | Significantly higher plantar pressures were observed beneath the lesser toes, second, third, fourth, and fifth metatarsal head areas and midfoot in the MTP I arthrodesis group. Evaluation of the pressure-time integral showed a significantly lower pressure-time integral in the hallux area, while a significantly higher pressure-time integral was observed in the fourth metatarsal and midfoot area in the MTP I arthrodesis group comparing to healthy controls. |

Abbreviations: Kinematic parameters (Kinem) – study in Tab. 3., Kinetic parameters (Kinet) – study in Tab. 4., Scale – study in Tab. 7.
*Purpose of the study, study group, test conditions/ equipment are in Tab. 3.

**Scales for Hallux Valgus and Hallux Rigidus**

For HV in seven papers different scales and angles were discussed (Tab. 7). HVA and IMA were evaluated in six articles [14,15,17,19,27,29], AOFAS scale was used also in six articles [14,17,19,27–29]. HVA and IMA significantly decreased after surgeries in all the articles that they were measured in. AOFAS results were also significantly better than the pre-operative ones. For HR AOFAS scale was used in four papers (Tab. 7.) [20,23,24] and the results increased post-operatively. HVA and IMA also significantly decreased in two articles [20,26]

For HV AOFAS scale was used in six out of seven papers and in all of them the results significantly increased [14,17,19,27–29]. HVA and IMA were also assessed in six articles and were significantly smaller postoperatively [14,15,17,19,27,29].

## Discussion

The purpose of this study was to review papers investigating kinematic and kinetic parameters during walking in patients after HV or HR surgeries to help improve understanding of how those surgeries influence gait biomechanics.

One of the most important goals of HV and HR surgeries is to regain ability to walk and perform activities of daily living without pain. Patients should be able to function better than before the surgery.

**Kinematic parameters for Hallux Valgus**

Kinematic analysis after HV surgeries was performed at different time intervals depending on the research. Klugarova et al. [18] tested patients 4 months after the surgery, whereas Canseco et al. [15] had their mean time of follow up 16 months, Moerenhout et al. [19] 12 months, Chopra et al. [17] 6 months. The conducted analysis showed that spatio-temporal parameters were worse [15,17,18] or the same as before the surgery [15,17,19]. Moreover, Klugarova et al. [18] proved that spatio-temporal parameters of the non-operated limb had also been affected. Lack of significant improvement in spatio-temporal parameters may suggest that the healing process may not have finished by the time of testing or the gait pattern had not been properly restored in the process of physiotherapy. The number of physiotherapy sessions e.g. 9 [17,19] may not be enough. It seems that surgery does not influence knee and hip biomechanics even when spatio-temporal parameters are disturbed.

**Kinematic parameters for Hallux Rigidus**

Due to a small number of papers comparing pre- and post-operative patients who underwent arthrodesis, it is hard to draw consistent conclusions. It seems that

**Tab. 7.** Data extraction from reviewed articles for HV and HR scales

| Study | Deformity | Intervention | Type of scale | Results |
|---|---|---|---|---|
| Martínez-Nova *et al.*, 2008 [27][HVPP, ††] | HV | DSTR-Akin procedure | HVA, IMA, AOFAS hallux metatarsophalangeal-interphalangeal | The average AOFAS score improved significantly post-op.<br>Mean HVA and IMA significantly decreased post-op. |
| Schuh *et al.*, 2009 [28][HVPP, ††] | HV | 10 scarf osteotomy<br>20 Austin osteotomy | AOFAS | The average AOFAS score improved significantly 6 months after surgery.<br>First metatarsophalangeal joint ROM increased at 6 months postoperatively, with a significant increase in isolated dorsiflexion. |
| Schuh *et al.*, 2010 [29][HVPP, ††] | HV | Chevron osteotomy | AOFAS<br>HVA,<br>IMA | The average AOFAS score improved significantly post-op.<br>Mean HVA and IMA significantly decreased post-op. |
| Martinez-Nova *et al.*, 2011 [14][HVPP, ††] | HV | Medial eminence of first MTH was removed, percutaneous distal soft tissue release (DSTR)-Akin procedure | IMA, HVA<br>AOFAS hallux–metatarsophalangeal–interphalangeal | The average AOFAS score improved significantly post-op.<br>Mean HVA and IMA significantly decreased post-op. |
| Canseco *et al.*, 2012 [15][HVKinem, †] | HV | No data | Changes in static deformity were evaluated based on measurements of the HVA and IMA on weight-bearing AP plain radiographs.<br>SF-36 Health Survey. | Mean HVA and IMA significantly decreased post-op. Average metatarsal length was also found to be significantly shorter.<br>SF-36, statistically significant improvement was seen in Physical Functioning. |
| Chopra, Moerenhout and Crevoisier, 2016 [17][HVkinem, †] | HV | Modified Lapidus procedure | AOFAS forefoot score and FAAM – activity of daily living (ADL).<br>IMA, HVA and distal metatarsal articular angle (DMAA). | Significant improvement in the IMA and HVA.<br>FAAM-ADL – no significant changes.<br>AOFAS – significant improvement in pain and function. |
| Moerenhout, Chopra and Crevoisier, 2019 [19][HVkinem, PP, †] | HV | Modified Lapidus procedure | AOFAS.<br>ADL part of the Foot and Ankle Ability Measure (FAAM).<br>IMA, HVA and distal metatarsal articular angle (DMAA) | The FAAM-ADL outcome reported non-significant improvement at 12 months. The AOFAS, reported significant improvement from six months onwards, and continued to show improvement at 12 months postoperatively.<br>Compared with the preoperative values, significant improvement was achieved in IMA and HVA at six months postoperatively. Values between six months and 12 months did not change significantly. DMAA showed no significant improvement postoperatively. |

**Tab. 7.** cont.

| Study | Deformity | Intervention | Type of scale | Results |
|---|---|---|---|---|
| Defrino *et al.*, 2002 [20] [HRkinem, HRkinet, HRPP, *] | HR | MTP I arthrodesis | AOFAS Hallux MTP-IP scale<br><br>Preoperative and post-operative radiographs were measured for IMA, HVA and interphalangeal/ Fitzgerald score. | The average AOFAS improved significantly post-op. Of the 10 arthrodesis procedures performed, four patients reported no pain, and minimal/occasional pain was reported in the other six.<br><br>The preoperative and postoperative values for the IMA and IP/Fitzgerald were not significantly different from each other. The HVA was significantly reduced postoperatively. |
| Brodsky *et al.*, 2007 [21] [HRkinem, HRkinet, *] | HR | MTP I arthrodesis | No data | There was no clinical or radiographic evidence of hallux interphalangeal joint arthritis at the time of final follow-up in any patient in the study. All patients responded that the operation had a positive effect on their lives and that given the same circumstances they would again choose to have surgery. |
| Nawoczenski, Ketz and Baumhauer, 2008 [22] [HRkinem, HRPP, *] | HR | Cheilectomy | VAS | At the time of the mid-term follow-up, the average postoperative VAS score ["worst pain"] was 5.1, representing an overall improvement of 20% in self-reported pain. |
| Canseco *et al.*, 2009b [23] [HRkinem, *] | HR | Cheilectomy | SF-36<br>AOFAS | The difference between preoperative and postoperative pain score was statistically lower post-op.<br>MTP I ROM was significantly greater post-op.<br><br>SF-36 score changes were not statistically significant. |
| Smith *et al.*, 2012 [24] [HRkinem, HRkinet, *] | HR | Cheilectomy | AOFAS | The average AOFAS score improved significantly post-op.<br><br>Clinical evaluation demonstrated significant changes in postoperative ROM of the MTP I joint and AOFAS Hallux scores. |
| Kuni *et al.*, 2014 [25] [HRkinem, *] | HR | Cheilectomy | AOFAS Hallux Metatarsophalangeal-Interphalangeal Scale | The average AOFAS score improved significantly post-op.<br><br>No significant difference in paint assessment could be detected pre and post-op. |
| Stevens *et al.*, 2016 [26] [HRkinem, HRPP, *] | HR | MTP I arthrodesis | IMA, HVA | Radiographic angles are presented in showing a significant decrease in IMA and HVA after MTP I arthrodesis. |

Abbreviations: HV kinematic parameters (HVkinem) – study in Tab. 2., HV plantar pressure (HVPP) – study in Tab. 5. †Purpose of the study for HV, study group, test conditions/ equipment are in Tab. 2. ††Purpose of the study for HV, study group, test conditions/ equipment are in the Tab. 5.

HR kinematic parameters (HRkinem) – study in Tab. 3., HR kinetic parameters (HRkinet) – study in Tab. 4., HR plantar pressure (HRPP) – study in Tab. 6. *Purpose of the study, study group, test conditions/ equipment are in Tab. 3.

some spatio-temporal parameters may be altered [21]. Increased time of single limb support and smaller step width may suggest that arthrodesis improves gait quality in patients with severe MTP I arthrosis and does not affect hip or knee kinematics [20,21,26]. The cheilectomy performed on patients with mild and moderate HR appears to be a valid procedure in case of gait kinematics. It significantly increases MTP I active range of motion in the sagittal plane [22,23,25]. The range of motion at MTP I in the coronal and transverse planes improves [22] or stays the same [23]. There are, however, differences in reports for spatio-temporal parameters: Canseco et al. [23] report significant improvements, Smith et al. [24] report no differences between pre – and post-operative analysis and Kuni et al. [25] report that the level walking speed did not change, but only eight patients were tested in that research.

**Kinetic parameters for Hallux Rigidus**

Ankle power during the push-off phase in a limb with fused MTP I is significantly lower than in a healthy limb [20], but compared to the pre-operative values it significantly increased [21]. Similar conclusions comparing pre – and post-cheilectomy patients were drawn by Smith et al. [24]. In case of arthrodesis and cheilectomy, it is possible that a decreased pain level allowed patients to walk freely without pain in the push-off phase connected with MTP I dorsiflexion. Pain usually occurs while osteophytes on the dorsal surface of the first metatarsal and proximal phalanx compress each other or irritate cutaneous nerves.

**Plantar pressure parameters for Hallux Valgus and Hallux Rigidus**

Patients with HV usually shift load to the lateral side of the foot and unweight hallux [30]. Therefore, increased mean contact area, maximal force and force time integral under hallux [28,29] suggest that first ray osteotomies positively affect gait biomechanics. Restoration of proper gait pattern is among the objectives of the rehabilitation process after HV and HR surgeries. One of its elements is to impose weight on the MTH I during the terminal stance phase, but it may sometimes be hard to achieve due to the characteristics of osteotomies. Osteotomies causes elevation of the MTH I and shortening of the first ray, which automatically causes unweighting of the MTH I during gait and increases amount of weight transferred by the MTH II. Decreased mean pressure under hallux after DSTR surgery may be explained by the fact that in HV lateral deviation is increased by the hallux abductor muscle which starts acting like a plantar flexor. Therefore, correction of the deformity should decrease pressure under the hallux. There are two different outcomes, increased and decreased parameters under the hallux after surgery, but then which outcome is really beneficial to the patient? To assess if change of the plantar pressure parameter is beneficial to the patient, we suggest that the results should always be compared with the control group. The closer the results to the control group, the better the treatment outcome is.

Plantar pressure analysis performed among patients with HR who were subjected to MTP I arthrodesis shows that this type of surgery reestablishes weightbearing function of the first ray and hallux [20]. However, it does not reestablish normal gait pattern [26]. According to Nawoczenski et al. [22] cheilectomy does not induce any significant plantar pressure changes.

**Scalesfor Hallux Valgus and Hallux Rigidus**

All HV surgical procedures included in this study significantly decreased HVA [14,15,17,19,27,29] and IMA [14,15,17,19,27,29]. What is more, AFOAS [14,17,19,27,29] score was significantly better after surgeries. HVA or IMA are less often measured in patients after HR surgical treatment. The main reason is that in HR deformity HVA and IMA are usually not significantly greater than in healthy people. In this group of patients AOFAS scores are significantly better postoperatively than pre-operatively [20,23–26].

One limitation of this study is the fact that most articles had a low number of participants. The other weaknesses of this study are incoherent age of participants in analyzed articles and different post-operative evaluation periods. Another drawback is comparison of studies where different procedures were used to treat patients with the same deformity, although we believe it is justified by a small number of articles on the topic and our awareness of the differences between procedures.

## Conclusions

Although HV and HR deformities are of the highest prevalence, there are very few research studies analyzing the influence of HV and HR surgeries on gait biomechanics. What is more, there are no articles available which would offer assessment of muscle activities. Such analyses could be important considering that patients after surgeries are wearing special post-operative shoes which are known to alter plantar pressure parameters [31]. Follow up assessment is usually performed many weeks after surgical procedure. Surgical treatment decreases pain and allows patients to perform activities of daily living. It also significantly improves IMA and HVA, especially in the HV group, but it does not normalize gait parameters. Lack of normalization of those parameters may be caused by lack of proper ROM in MTP I, subconscious unweighting of the first ray, lack of muscle strength or pain at the end of MTP I range of motion during toe-off. All those factors may be due insufficient physiotherapy or imperfections of surgical procedures. We think that a comprehensive research on a large group of patients after similar procedures and with a longer physiotherapy process is needed. In our opinion, such research should include kinetic and kinematic analysis of gait as well as muscle activity and plantar pressure assessment pre- and post-operatively with reference to the control group. Future research should be focused on group homogeneity in terms of age and type of surgery.

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**Conflicts of interest**
The authors declare no conflict of interest.

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