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Original Research

Validity of the Most Common Footprint Indices in Measuring Medial Longitudinal Arch in Comparison with a Radiographic Method as a Gold Standard

Mahsa Hakimi Poor[1], Hooman Minoonejad[2], Reza Rajabi[3], Seyed Hamed Mousavi[4*]

1. Department of Health and Sports Medicine, Faculty of Physical Education and Sport Sciences, University of Tehran, Tehran, Iran. Email: M.hakimipoor@yahoo.com, ORCID:0000-0001-8468-6473.

2. Department of Health and Sports Medicine, Faculty of Physical Education and Sport Sciences, University of Tehran, Tehran, Iran. Email: H.minoonejad@ut.ac.ir, ORCID: 0000-0002-5983-8102.

3. Department of Health and Sports Medicine, Faculty of Physical Education and Sport Sciences, University of Tehran, Tehran, Iran. Email: rrajabi@ut.ac.ir, ORCID:0000-0002-0464-5688.

4. Department of Health and Sports Medicine, Faculty of Physical Education and Sport Sciences, University of Tehran, Tehran, Iran. Email: musavihamed@ut.ac.ir, ORCID:0000-0003-2906-2101.

ABSTRACT

Measurement of the medial longitudinal arch (MLA) of the foot is a controversial issue in orthopedics. Using footprint parameters is considered as the most common method to evaluate MLA. Present study aimed to determine validity of footprint indices in measuring medial longitudinal arch in comparison with radiography method. Forty-one subjects were randomly selected. Footprints were recorded in static bipedal standing position using ink and paper. Arch index, footprint index, Chippaux-Smirak index, and Staheli index were calculated from the footprints. Also, calcaneal inclination, calcaneal-first metatarsal, talo-calcaneal angles and navicular height were obtained from lateral feet radiographs as a golden standard method for evaluating the static posture of the foot. All measurements of footprints and radiographs were calculated by a technique in computerized image analysis based on Adobe Photoshop software. Pearson correlation coefficient was used to determine validation. Results showed a strong relationship between the values of footprint indices and calcaneal inclination angle, calcaneal-first

metatarsal angle and talo-calcaneal angle obtained from radiography (r=0.56 to 0.72). The highest correlation coefficient (r = 0.72) was observed between Staheli index and calcaneal inclination angle and the lowest correlation coefficient (r=0.56) was between the arch index and calcaneal inclination angle whereas no significant relationship was found between footprint indices and navicular height obtained from radiography. Analysis of footprint indices had an acceptable validity in measuring the medial longitudinal arch. Therefore, this method is recommended to be used as a valid, non-invasive, quick, cost-effective and accurate method for measuring MLA.
Keywords: Acceptability, Foot arch, Measurement, X-ray, Pronation

Corresponding Author: Seyed Hamed Mousavi, Department of Health and Sports Medicine, Faculty of Physical Education and Sport Sciences, University of Tehran, Tehran, Iran. Email: musavihamed@ut.ac.ir. Tel: +989171542600

INTRODUCTION

As foundation of the body, the foot forms the most important mechanical interface between body and the ground and surrounding environment, and its shape and structures plays an important role in transferring the amount and direction of the forces imposed on other joints and parts of the body [1]. So foot dysfunction and malalignment is related to decreased function or injury throughout the whole lower limb and even other parts of the body [2, 3].

Multiple function of the structures of the foot such as absorption and distribution of ground reaction forces and its adjustment with different surfaces and maintenance of one's stability depends on existence of foot arches. The height of the medial longitudinal arch (MLA) is the most important reference to assess foot problems and maintaining optimal function of foot [4]. Correct arch of the foot is necessary, both for keeping a stable upright posture, locomotion and ensuring proper quality of life[5].

Many studies referred to the effect of height of medial longitudinal arch on motion in lower extremities [6, 7], balance ability [8, 9], pain in foot, leg and low back[10], and predisposition to overuse injuries [3, 11]. The first and the most important measure for preventing from and decreasing the problems arising from foot disorders is accurate assessment of foot arch, especially in younger people, because delayed diagnosis will result in clinical symptoms in adulthood while necessitating much more invasive treatment procedures. Despite the high level of interest in the function of the arch, there is still considerable disagreement regarding how to measure arch structure and how to categorize foot type. There are various methods proposed for measurement of the MLA [5, 12, 13]. These can be classified as direct and indirect methods. Direct methods include anthropometric measurements and radiographic evaluations [12, 14]. Indirect methods include footprint and photographic analyses [12, 15-17]. Golden standard method for assessment of foot is to use radiographies [4]. But, considering the potential risks and high expenses of this method, especially in repeated measurements, it is not appropriate to use this method more often [18].

Footprint analysis as a simple, non-invasive, easily available and cost-effective method, which is still the most popular to analyse and assess the MLA Foot problems such as pes cavus and pes planus are frequently seen in clinical practices and researches [16, 19, 20].

Analysis of footprint parameters in order to evaluate medial longitudinal arch, with arch index, footprint index, Staheli index, and Chippaux-smirak index being among the mostly applied indices in previous studies [19, 21]. Accordingly, some studies have been conducted to determine validity of the indices. Kanatli et al. (2001) reported a significant relationship between Staheli index and calcaneal-first metatarsal angle and talo-horizontal angle by using lateral radiography. They recommended this method as an alternative non-invasive and valid method for assessment of medial longitudinal arch. As mentioned, only one footprint parameter, i.e. Staheli index, was validated in this study[22]. Villarroya et al. (2009) in their study on the overweighed children, observed a significant relationship between Chippaux-smirak index and

footprint angle by pedograph and calcaneal inclination angle and calcaneal-first metatarsal angle by radiography [20].
Also, Yalçin et al. (2010) in their study reported a significant relationship between calcaneal-first metatarsal angle and talo-horizontal angle and arch index, while no significant relationship was found between calcaneal inclination angle and talocalcaneal angle and arch index. It is necessary to note that force platform was used in this study in order to obtain arch index [12]. Gutie´rrez et al. (2015) recorded footprint indices such as Chippaux-smirak, Herna´ndez-Corvo, and Staheli indices by pedograph and then investigated the relationship between values of these indices by using manual method and Photoshop Software. Results of their study indicated that there was no significant difference between the values obtained from both methods [23].
In another study, Menz and Munteanu (2005) examined the validity of some clinical methods for foot assessment and radiography in the elderly by using carbon paper. In order to analyze foot, they calculated calcaneal inclination angle, calcaneal-first metatarsal angle and navicular height by using lateral radiography of foot. Results of their study indicated that arch index (r= 0.51-0.70), footprint index (r= 0.42-0.59) and navicular height (r=0.43-0.79) had moderate to good correlation coefficients with the variables measured by lateral radiography [24].
In general, by reviewing the literature on study background, it is seen that there is limited information about validity of footprint index in measuring medial longitudinal arch in spite of high use of footprint indices on one hand, and in the same number of limited studies on validity of footprint indices, either the people have been assessed only by one or two indices related to footprint, or different methods and instruments such as pedograph, force platform and photography have been used, on the other hand. Considering the foregoing, it seems necessary to determine validity of measurement of common footprint indices by using traditional method (ink and paper) as the cheapest, most common and most accessible method for recording footprint. Hence, the aim of this study was to determine validity of common footprint indices in comparison with radiography method (golden standard method for assessment of foot arches).

MATERIAL AND METHODS

Participants

The studied sample consisted of 41 subjects including 22 men (age: 22.8±2.2 years, height: 177.7±5.69 cm, weight: 68.1±10.6 kg) and 19 women (age: 25.7±2.71 years, height: 165.9±5.76 cm, weight: 60.1±9.76 kg), who referred to a radiography center to have lateral radiography of foot as prescribed by a specialist (orthopaedist). Each subject signed the inform consent to participate in the trial approved by the ethics committee of the University of Tehran and followed the principles of the Helsinki's declaration. Exclusion criteria included a history of fracture, ankle and foot surgery [25], neurological disorders, BMI lower than 18 and/or higher than 25 [26], lesion and callus and/or pain on test day, which influenced standing posture of the subjects [16].

Procedure

All participants were right-footed as determined by kicking a ball [27]. In order to take footprint of the subjects, they were asked to place their right foot on the special researcher-made stamp or ink pad (containing water-soluble ink) while in a sitting position, so that all parts of the sole are impregnated with the ink. Then, by placing a special graph paper for recording footprint under right foot, the subjects were asked to stand while their knees are extended and body weight is distributed equally on both feet [17]. After lifting the foot, in order to avoid from any probable change, the footprint were delimitated by the researcher. Then, the concerned indices were calculated by the researcher, including arch index: ratio of medial one third of foot to total footprint without toes [4], Staheli Index: ratio of the narrowest width of arch to the widest width of heel [15], footprint index: ratio of non-contact area of sole to the contact area of sole excluding toes [4], and Chippaux-smirak Index: ratio of the narrowest width in arch to the widest frontal width of foot [16] (Figure 1).

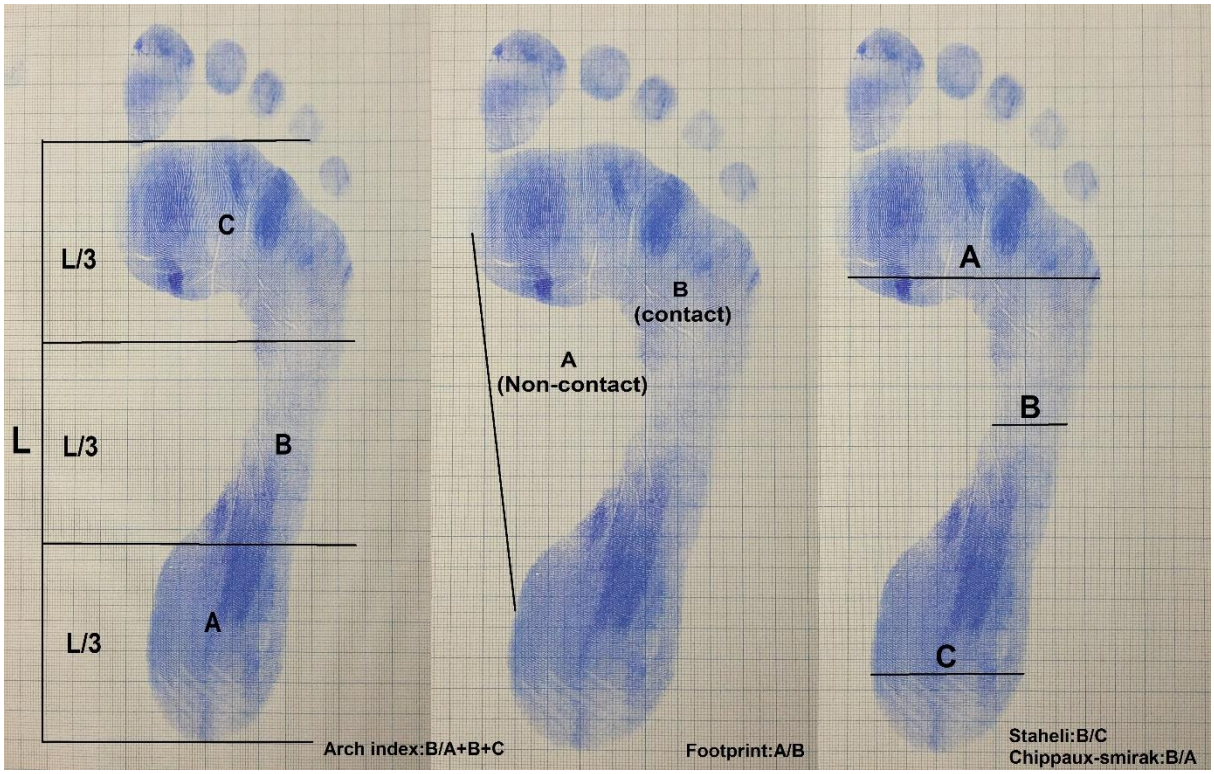

Figure (1). Calculation of the Arch Index: B/A+B+C, Footprint Index: A/B, Staheli Index: B/C, Chippaux-smirak Index: B/A obtained from ink footprints

In this study, in order to determine validity of the common footprint indices, lateral radiographs were used while the weight is distributed equally on both feet [17]. As frequently used in previous studies for direct measurement of medial longitudinal arch [4, 17, 24, 25], the following variables were calculated by the researcher by using Foxit Reader Software: A) Calcaneal inclination angle: the angle between the tangent to the inferior anterior surface of the calcaneus and the platform on which the foot is resting (CAI Angle), B) Calcaneal-first metatarsal angle: the angle subtended by the tangent to the inferior surface of the calcaneus and the line drawn along the dorsum of the midshaft of the fist metatarsal (CA-MT1 Angle), C) Talo-calcaneal angle: The angle between the tangent to the inferior anterior surface of the calcaneus and longitudinal axis of the talus (TC Angle), and D) Navicular height: distance from inferior tubercle of the navicular bone to the horizontal line (NH) [1, 10] (Figure 2).

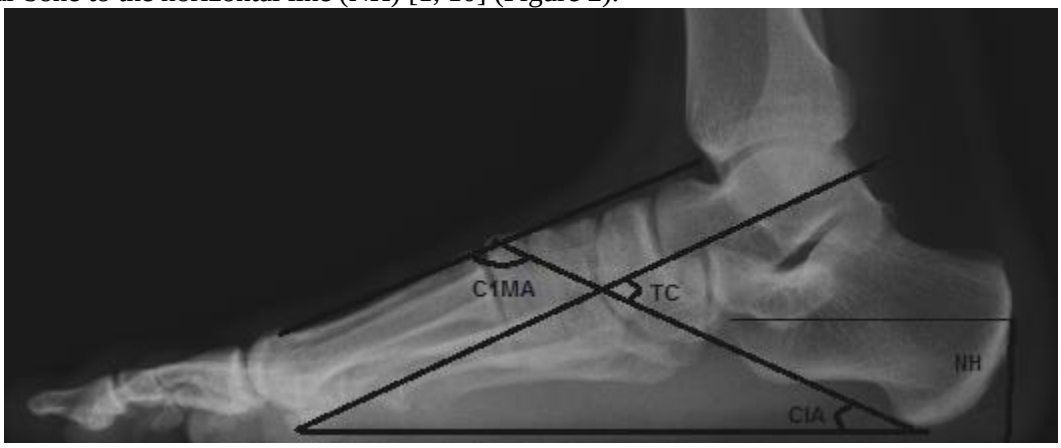

Figure (2). Arch measurements obtained from lateral radiograph.

Abbreviations: C1MA, calcaneal first metatarsal angle; CIA, calcaneal inclination angle; NH, navicular height ; TC, talo-calcaneal angle

Data analysis

All data were tested for normality using the Kolmogorov-Smirnov test. Pearson's correlation coefficient was used to determine validity (investigation of the relationship between values of the indices measured by ink and radiographs). Correlation coefficients (r) between 0 and 0.1 were considered as weak, between 0.1 and 0.3 as modest, between 0.3 and 0.5 as moderate, between 0.5 and 0.8 as strong, and between 0.8 and 1 as very strong [28]. All statistical analyses were performed by SPSS, Ver. 22, at significance level of α=0.05.

RESULTS

The study sample included 41 individuals: 22 men (age: 22.8±2.2 years, height: 177.7±5.69 cm, weight: 68.1±10.6 kg) and 19 women (age: 25.7±2.71 years, height: 165.9±5.76 cm, weight: 60.1±9.76 kg). Descriptive statistics for each of the footprint indices and radiographic parameters are shown in Table 1.

Table 1. Descriptive statistics of footprintindices and radiographic parameters

Parameters	mean ± SD	Range
Footprint indices		
AI	**23.03 ± 0.03**	**0.16 - 0.32**
SI	**0.65 ± 0.12**	**0.45 - 0.98**
FPI	**0.31 ± 0.09**	**0.08 - 0.5**
CSI	**0.39 ± 0.09**	**0.27 - 0.6**
radiographic parameters		
CIA (°)	**23.52 ± 4.64**	**12.47 - 33.52**
C1MA (°)	**133.1 ± 7.1**	**118.87 - 150.87**
TC (°)	**47.28 ± 6.15**	**31.25 - 58.27**
NH (mm)	**20.34 ± 3.29**	**13.09 - 25.87**

Abbreviations: AI, arch index; C1MA, calcaneal first metatarsal angle; CIA, calcaneal inclination angle; CSI, chippaux-smirak index; FPI, Footprint index; NH, navicular height; SI, staheli index; TC, talo-calcaneal angle.

Correlations among the footprint and radiographic measurements are shown in Table 2. All Footprint indices demonstrated significant relationship (r=0.56-0.72), with the calcaneal inclination angle, calcaneal-first metatarsal angle and talo-horizontal angle by radiography, but no significant relationship was found between footprint indices and navicular height by radiography($p>0.05$). The highest correlation coefficient was observed between Staheli index and calcaneal inclination angle (r=0.72).

Table 2. Pearson r correlation values* among footprint indices and radiographic parameters

Footprint indices	Radiographic parameters							
	CIA		C1MA		TC		NH	
	R	P	R	P	R	P	R	P
AI	**-0.56**	**0.009**	**0.57**	**0.009**	**-0.66**	**0.002**	**-0.30**	**0.19**
SI	**-0.72**	**0.001**	**0.64**	**0.002**	**-0.70**	**0.001**	**-0.34**	**0.13**
FPI	**0.71**	**0.001**	**-0.69**	**0.001**	**0.69**	**0.001**	**0.39**	**0.09**

CSI	**-0.67**	**0.001**	**0.63**	**0.003**	**-0.69**	**0.001**	**-0.21**	**0.36**

Abbreviations: AI, arch index; C1MA, calcaneal first metatarsal angle; CIA, calcaneal inclination angle; CSI, chippaux-smirak index; FPI, Footprint index; NH, navicular height; SI, staheli index; TC, talo-calcaneal angle.
* Significant at P<0.05 for all values

DISCUSSION

This study aimed to determine validity of common footprint indices by calculating correlation between the indies obtained from footprint record and those obtained from lateral photography of foot. As Table 1 shows, arch index is 0.23±0.03 in the present study. Cavanagh and Rodgers (1987) [29], Menz and Munteanu (2005) [24] and Queen et al. (2007) [16] also reported the similar results for arch index in adult age group (0.23±0.05, 0.24±0.05, and 0.21±0.6, respectively). Furthermore, values of Staheli, footprint and Chippaux-smirak indices in the present study (0.65±0.12, 0.31±0.09, and 0.39±0.9, respectively) were similar to those in the study of Queen et al. (2007), who reported mean values of 0.41±0.24, 0.38±0.13 and 0.27±0.15 for Staheli, footprint and Chippaux-smirak indices, respectively, in 30 women and men [16]. In general, values of the investigated footprint indices are similar to the results of previous studies, and the existing small difference may be due to the difference in number of samples. As it can be seen from Table 1, mean (± standard deviation) of the variables obtained from lateral photography of foot was 20.34±3.29 mm for navicular height, 23.52±4.64 degree for calcaneal inclination angle, and 133.1±7.1 degree for calcaneal-first metatarsal angle. In previous studies, values of these variables were also reported to be very similar to those in the present study; for example, in their study on the elderly, Menz and Munteanu (2005) reported 21±7 degree for calcaneal inclination angle and 133±9 degree for calcaneal-first metatarsal angle by using lateral photography [24].

Results of Pearson correlation test (for investigation of validity of footprint indices and radiography) indicated that there was a significant relationship between the results obtained from footprint indices and those obtained from radiography ($p<0.05$). As it can be seen from Table 2, the correlation coefficient between the variables obtained from footprint record and radiographic indices ranges between 0.72 and 0.56, and the highest correlation coefficient (r=0.72) was observed between Staheli index and calcaneal inclination angle and the lowest correlation coefficient (r=0.56) between arch index and calcaneal inclination angle. Generally, all four measured indices, i.e. Staheli, footprint, Chippaux-smirak and arch indices, had correlation coefficient (r) of -0.72, 0.71, -0.67 and -0.56 with calcaneal inclination angle (CAI), correlation coefficient (r) of 0.64, -0.69, 0.63 and 0.57 with calcaneal-first metatarsal angle (CA-MT1), and correlation coefficient (r) of -0.70, 0.69, -0.69 and -0.66 with talo-calcaneal angle (TC) obtained from radiography, respectively. Obtained correlation coefficients are indicative of a strong relationship between footprint indices and the indices measured by radiography.

The present study indicated that Staheli index had a significant relationship with calcaneal-first metatarsal angle, calcaneal inclination angle and talo-calcaneal angle obtained from radiography. Kanatli et al. (2001) also reported a significant relationship between Staheli index in recording footprint by Harris Beath mat method and calcaneal-first metatarsal angle (r=0.45) and talo-horizontal angle (r=0.40) (using radiography) [22]. Among other results of the study, a significant relationship between arch index and Chippaux-smirak index and calcaneal-first metatarsal angle, calcaneal inclination angle and talo-calcaneal angle can be mentioned, which is consistent with the study conducted by Villarroya et al. (2009), who reported a significant relationship between Chippaux-smirak index and calcaneal inclination angle and calcaneal-first metatarsal angle by radiography [20]. Furthermore, in their study, Yalçin et al. (2010) also reported a significant relationship between calcaneal-first metatarsal angle and talo-horizontal angle and arch index, while there was no significant relationship between calcaneal inclination angle and talocalcaneal angle and arch index [12]. It is necessary to note that force platform was used in this study in order to obtain arch index, although pedograph and force platform were used for recording footprint in these studies,

respectively.
In the present study, no significant relationship was found between four indices measured by recording footprint and navicular height obtained from radiography ($p<0.05$). Previous studies also reported weaker correlation between navicular height and other indices as compared to other radiography variables [24, 30], which, in the opinion of the authors of the present paper, may be attributed to the difficulty in accurate detection of right location of navicular bone in lateral radiographs. Considering the correlation coefficients of 0.72 to 0.56, which is indicative of a strong relationship between values of arch index, Staheli index, Chippaux-smirak index and footprint index and variables of lateral radiography of foot, it can be said that common footprint indices can measure medial longitudinal arch more accurately and precisely than radiography does.

CONCLUSION

High validity of common footprint indices as compared to lateral radiography of foot indicates accuracy and precision of such indices in measuring medial longitudinal arch, which is very essential and important for any device or method used to measure different variables. According to high validity of footprint indices and also affordability and ease of administration without need to a special tool, clinicians and researchers may use footprint indices used in this research in their clinical and research practices.

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مهسا حکیمی پور[۱]، هومن مینونژاد[۱]، رضا رجبی[۱]، سید حامد موسوی*[۱]
۱. گروه بهداشت و طب ورزشی، دانشکده تربیت بدنی و علوم ورزشی، دانشگاه تهران، تهران، ایران

چکیده:
استفاده از شاخص های اثر پا به عنوان متداول ترین روش برای ارزیابی قوس داخلی پا ، مشخص کردن ناهنجاری ها پا و پیگیری روند درمان شناخته می شود. هدف از مطالعه حاضر تعیین روایی شاخص های رایج اثر پا در مقایسه با روش رادیوگرافی بود. در این مطالعه توصیفی- همبستگی تعداد ۲۱ نفر آزمودنی مرد و زن به صورت تصادفی از میان جامعه آماری انتخاب شدند. ثبت اثر پا بوسیله جوهر و محاسبه شاخص های رایج اثر پا بوسیله نرم افزار Adobe Photoshop انجام گرفت. از رادیوگرافی جانبی پا به عنوان استاندارد طلایی به منظور سنجش روایی شاخص های اثر پا استفاده شد. برای تعیین میزان روایی از ضریب همبستگی پیرسون استفاده شد. نتایج نشان دادندکه بین مقادیر شاخص های اثر پا و زوایه انحراف پاشنه، زاویه پاشنه-متاتارس اول و زاویه تالوهوریزنتال حاصل از رادیوگرافی روایی قوی وجود دارد (r=۰/۷۲تا۰/۵۶). بیشترین ضریب همبستگی بین شاخص استاهلی و زاویه انحراف پاشنه (r=۰/۷۲) و کمترین ضریب همبستگی بین شاخص قوس و زاویه انحراف پاشنه مشاهده شد (r=۰/۵۶)، اما ارتباط معناداری بین شاخص های اندازه گیری شده با ارتفاع ناوی حاصل از عکس رادیوگرافی دیده نشد. نتایج این تحقیق نشان دادند که تجزیه و تحلیل شاخص های اثر پا دارای روایی قابل قبول برای اندازه گیری قوس طولی داخلی می باشند، لذا استفاده از این روش به عنوان شیوه ای معتبر و غیر تهاجمی برای اندازه گیری شاخص های اثر پا توصیه می شود.

واژه های کلیدی: روایی، شاخص های اثر پا، قوس کف پا، رادیوگرافی، پرونیشن