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Quantifying Conformation of the Equine Digit from Lateromedial Radiographs

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Introduction

Equine practitioners are regularly asked to assess foot conformation in the standing horse as it relates to the animal's intended athletic pursuit. The process is subjective and largely based on the individual's previous experience with similarly conformed animals in the same athletic endeavor. No quantitative assessment is regularly made of the hoof capsule and the boney column within it. This paper offers a standardized method by which exact measurements can be quickly made of both anatomical components using radiographs and photographs and then recorded to a database for comparison to other horses and for future reference as changes are made to the individual patient. This offers practitioners a well-defined and consistent way to communicate concerning the conformation for the equine digit.

When radiographs are used for conformational purposes, typically one hears any of several non-scientific terms, such as "broken pastern angle", "rotated P3", "sinker", "flared wall", and so forth. We propose a well-defined and repeatable way to measure various quantities in the lateromedial radiograph of the equine digit. Our hope is to give a common definition to various measures of hoof and bone conformation. Such a quantification will prove useful in tracking changes, communicating between various practitioners, and in future veterinary studies.

Having established a well-defined set of parameters, many possibilities for their use become apparent. One use is in making comparisons between horses. This can be extremely useful in assessing how a particular horse compares to a certain control group. Another use of the parameters is in tracking change in conformation. As a part of preventative foot care, or in concert with an attempt to improve the conformation of the hoof, such a system is invaluable in tracking progress, or lack of it, in an unbiased way. Another use of the parameters is in a scoring system which rates a given set of parameters relative to some ideal. Such a use is of course subjective and judges the conformation relative to a certain practitioner's opinion of what constitutes good conformation.

Methods

While the method outlined in this paper could be followed using a radiograph, a ruler, and a compass, a software implementation[a] is available which makes the technique much easier and more automatic. One begins by digitizing the radiographic image, either with a transparency scanner, or by photographing the radiograph placed on a lightbox with a digital camera. The image is then loaded into the software package, which then guides the user to pick certain key points in the image, from which a set of parameters is computed.

The main contribution of the method is a well-defined way to measure angulation of the bone column, as well as a set of other measures of interest. This technique of assigning joint-angles in a well-defined way, and with a certain positive sense, follows closely methodologies in use in the engineering field of robotics[1].

Parameters Specifying the Angulation of the Phalanges

We start by establishing a line segment on the lateral image of the distal phalanx (P3) for use as a reference, useful when quantifying the orientation of P3. The line segment is defined by two points which specify it's end points. First we pick a point at the "tip" of P3, that is, at the extreme distal-palmar portion of the bone as seen in the lateral radiograph. Second, we pick a point in the "lowest point" in the dip on the dorsal surface of P3 just below the extensor process. These two points, and the line segment which connects them are shown for a typical case in figure 1.

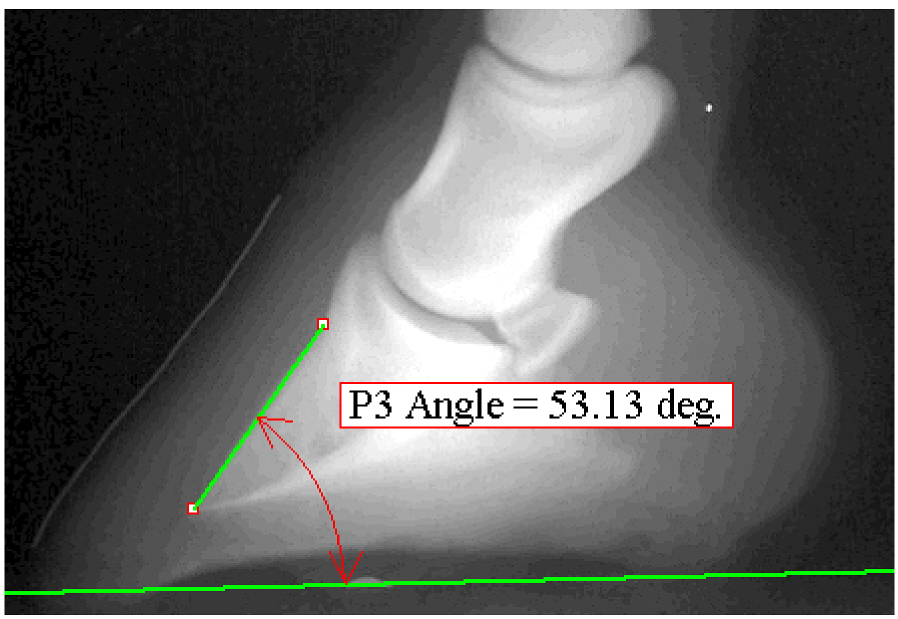

Figure 1: Establishing a line segment on P3 for use as an orientation reference.

We choose these two points in particular for the following reasons. First, a line segment which generally lies along the dorsal surface of P3 (in the lateral view) is generally accepted by practitioners as an important line. Often this line is compared to the line at the dorsal hoof wall when looking for signs of P3 rotation, or when recommending hoof trimming based on radiographic views. Secondly, these two points are quite well-defined and easy for all practitioners to locate in a radiograph. In some cases involving pedal osteitis and bone-remodeling at the tip of P3, the first point may not be as well-defined as we would like. In such cases, an attempt to assign the point so that the line segment approximates the dorsal shape of P3 is an appropriate approximation. Note that the length of this line segment is not used by our method, only its orientation.

In figure 1 we show the angle between this reference line segment and the ground surface. In order to easily see the ground surface in a radiograph, it is helpful if a piece of metal (or other radio-opaque object) is placed on the support surface when the radiograph is taken. We call the angle shown in figure 1 the "P3 Angle", and it is an important parameter as regards changes in the orientation of P3 related to laminitis or other problems.

The next step in establishing reference geometry for the phalanges has to do with fitting circles to the distal ends of the middle phalanx (P2) and the proximal phalanx (P1). Any three points which lie on the distal end of P2, and which lie within the joint space of the coffin joint, uniquely define a circle. Likewise, three points picked at the distal end of P1, and within the joint space of the pastern joint, uniquely define a circle at that joint. Figure 2 shows such circles for a typical case.

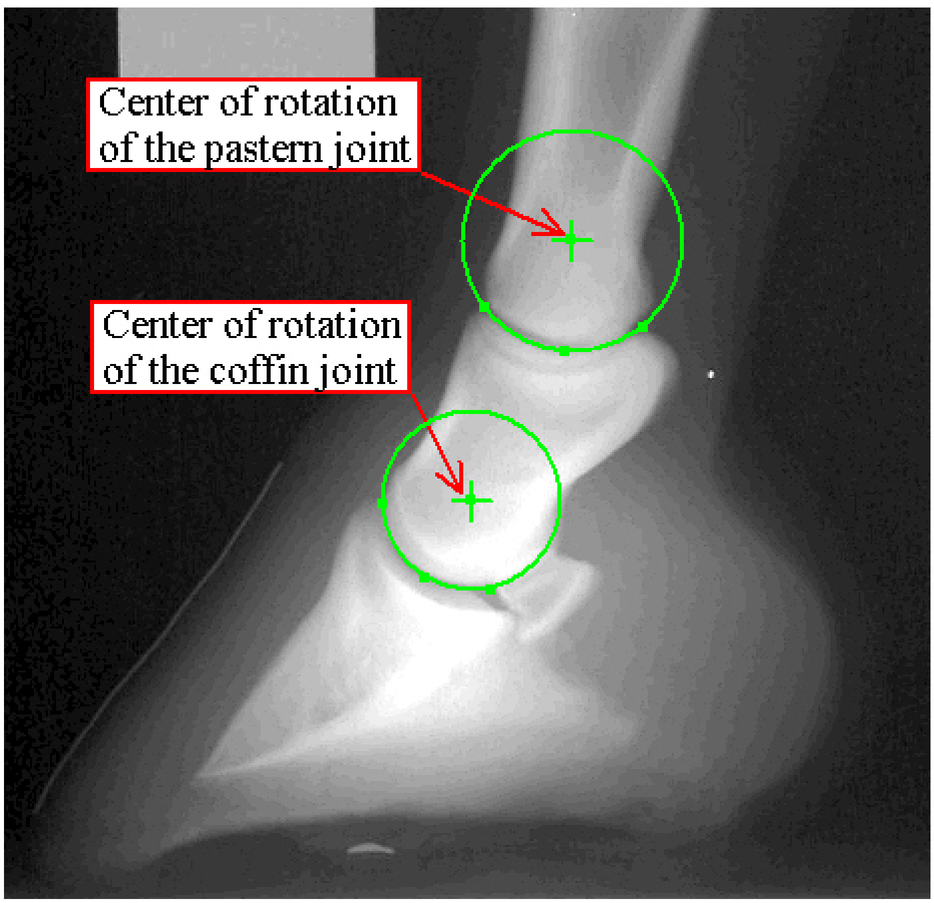

Figure 2: Circles defined by three points at the distal ends of P1 and P2.

The shape of a biomechanical joint, viewed in the plane perpendicular to the joint's axis, is circular, at least in a region local to the joint's nominal operating point. Only for large rotations of the joint may the circular approximation lose validity. That is to say, in it's normal range of operation, the coffin joint articulates P3 about a fixed center of rotation located on P2 as indicated in figure 2. Likewise, the center of rotation for P2 about the pastern joint is a point located on P1 as indicated in figure 2.

Note that the biomechanical motion of the limb involves rotations at these two centers as well as others found in the proximal direction up the limb (e.g., at the fetlock joint, at the carpus, etc). The notion of "center of articulation of the foot" that is sometimes mentioned is hence not well defined, as the foot articulates due to several rotation centers. Only with a gross simplification can we speak of a single "center of articulation" for the foot. One such simplification apparently sometimes used, is to assume no motion at the pastern joint and other more proximal joints, and refer the center of rotation of the coffin joint as the "center of articulation" of the foot.

While it would make sense to repeat the circle-fitting procedure at the fetlock joint, in standard practice, many radiographs of the digit do not fully capture the fetlock joint. Instead, we propose a method of defining an "axis of P1" which we will later use in defining the angular position of the pastern-joint. This technique is as follows: Having found the center of rotation associated with the pastern joint, we construct a larger circle of 3 times the radius of the original circle, overlay this circle on the image, and pick the two points where this circle crosses P1 as viewed from this lateral aspect. This defines a line segment. We use the midpoint of this line segment as a point that we will consider to be on the "axis of P1". By "axis of P1" we mean a line which is aligned with the major dimension of P1 as viewed in a lateral radiograph and which is centered within P1. We use this point, along with the center of rotation of the pastern joint (as defined previously) to define the "axis of P1". We will use this axis as a means to describe the orientation of P1 in the lateral radiograph.

We may now define a precise way to measure value the rotational position of coffin joint and of the pastern joint as seen in lateral radiographs. In figure 3 we show these joint-angle values. To quantify the coffin-joint angle, construct a line from the rotation center associated with the coffin joint extending down towards the sole and parallel to our reference orientation defined on the dorsal aspect of P3. The value of the coffin-joint angle is the geometric angle formed between this constructed line, and the line defined by connecting the two rotation centers. In the example shown in figure 3, this value is 15.22 degrees. The positive sense is defined such that a positive rotation of the coffin-joint makes the major axis of P2 become more upright in the image.

To quantify the pastern-joint angle, construct a line that connects the two rotation centers. The value of the pastern-joint angle is the geometric angle formed between this constructed line and the line representing the "axis of P1" as previously defined. In the example of figure 3 this value is 7.61 degrees. The positive sense is defined such that a positive rotation of the pastern-joint makes the axis of P1 become more upright in the image.

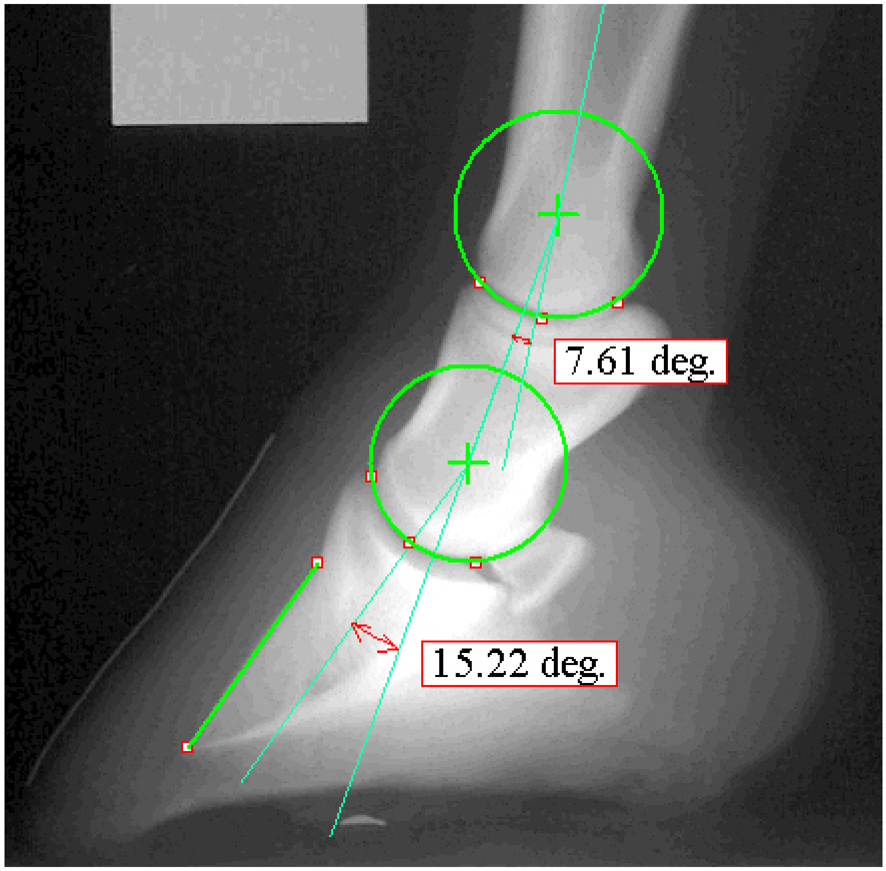

Figure 3: Definition of the coffin-joint angle and the pastern-joint angle.

We have defined the "P3 Angle" (see figure 1), the "coffin-joint angle" and the "pastern-joint angle" (see figure 3) such that they may be summed to obtain the angle of P2 relative to ground, and a value for the angle of P1 relative to ground. For example, in the case shown in figures 1 and 3, we compute the orientation of the axis of P1 relative to ground as 53.13 + 15.22 + 7.61 = 75.96 degrees.

Parameters Involving Length Measurements

In addition to the parameterization of the angulation of P1, P2, and P3 described in the previous section, it may also be useful to develop a well-defined, standard method of measuring the relationship between the exterior hoof wall and the phalanges which may involve length measurements. This can be done by means of a set of additional parameters, a sample of which are shown in figure 4.

The parameter "P3 Descent" gives a measure of the distance from the highest point on the extensor process of P3 to the hairline on the exterior of the hoof capsule. The parameters "P3 to Toe" and "P3 to Ground" may be of interest to a farrier in deciding how much toe to trim. The "Length of P2" is defined as the distance between the centers

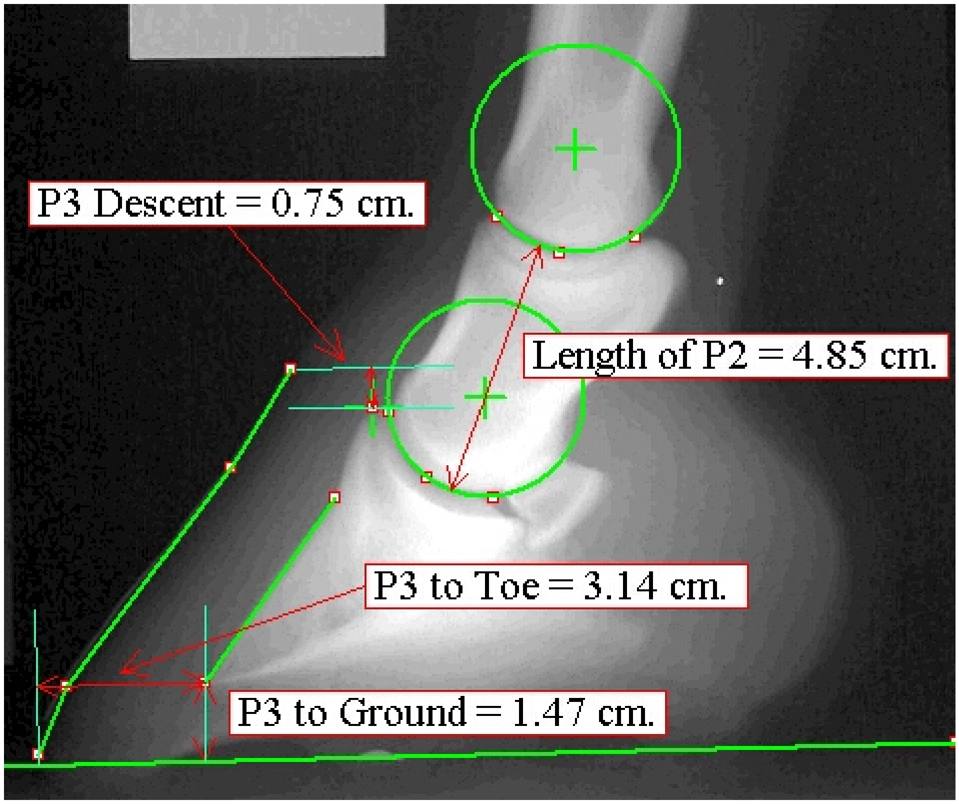

Figure 4: An example showing four length parameters

of the two fit circles (defined previously), minus the radius of the circle at the pastern joint, and plus the radius of the circle at the coffin joint.

For measurements taken from radiographs to be considered accurate, a number of factors must be considered. Chief among these factors is the careful set up of the radiographic machine, the subject, and the film. In the case of the lateromedial radiograph, we wish to mark the dorsal hoof wall with radio-opaque material, place a metal marker in the block on which the horse stands to be able to see the "ground plane" in the resulting image, and so on. The central X-ray beam should be parallel to the bulbs so that it is perpendicular to the plane the leg moves in. These and other important aspects of good technique have been documented elsewhere[2].

Additionally, when it is desired to make measurements of lengths, an additional calibration technique must be used. All radiographs exhibit a certain degree of magnification. The amount of magnification present depends on the distance from X-ray point source to the film, known as the Film-Focal Distance (FFD), and the distance between the film and the subject, which we will call the Object-Film Distance (OFD). To be more precise, we define OFD as the distance from the film to the *center of the bone column*. The magnification factor, M, for a given image is then computed as:

$$M = \frac{FFD + OFD}{FFD}$$

By applying the inverse of this value to all length measurements made in the image, we obtain length values which have been scaled to the center of the bone column. Hence values such as those shown in figure 4 are understood to be length measures at the center of the leg.

Results

Having established a well-defined set of parameters, many possibilities for their use become apparent. One use is in making comparisons between horses. This can be extremely useful in assessing how a particular horse compares to a certain control group. For example, as part of a pre-purchase examination, one could compare the parameters of the subject horse to those of a control set of 100 horses of the same breed which were previously judged sound by veterinarians performing pre-purchase examinations. Such data would be interesting and valuable for the buyer, and would further protect the veterinarian as it helps make a more complete disclosure concerning the subject horse.

A major use of the parameters is in tracking change in conformation. As a part of preventative foot care, or in concert with an attempt to improve the conformation of the hoof, such a system is invaluable in tracking progress, or lack of it, in an unbiased way. One such use of the system has been for making periodic adjustments to the “rails” of a special shoeing system used in conjunction with a case of severe laminitis in which careful and measurable angular changes to P3 were introduced over time to slowly change angulation.[b] We feel that any attempt at corrective shoeing would benefit from tracking changes to these conformation parameters.

Another use of the parameters is in a scoring system which rates a given set of parameters (equivalently the set of parameters can be thought of as a description of one individual’s *conformation*) relative to some ideal. Such a use is of course subjective and judges the conformation relative to a certain practitioner’s opinion of what constitutes good conformation.

Repeatability of the Method

It can be difficult to achieve consistency in radiographs of live horses for a number of reasons. In addition, a user of our method introduces an additional source of non-repeatability when picking the key points in the radiograph.

By ***repeatability*** we mean the ability of the technique to derive the same parameter values from different radiographs of the same horse, as well as the ability for different practitioners to derive the same parameter values from the same radiographic image. Hence two tests were performed: in the first test, the technique was used by a single practitioner to measure a certain biomechanical parameter in eight radiographs of the same equine digit, taken over several years by various independent radiographers. Variation in the measured parameter indicate that we can derive highly repeatable parameter values in such a situation. In the second test, the same radiographic image was analyzed using our technique by thirteen different practitioners working independently. Variation in measured parameters indicate good repeatability of results in this situation.

In the first test, we estimate the repeatability of our method for length measurements as follows. Eight radiographs of the right fore digit of the same horse, taken over a ten year period (1991 – 2001), were parameterized using our technique. The horse's age was 7 in 1991, and so could be considered fully mature when the first radiograph in the study was taken. The 8 radiographs were taken by 4 different practitioners using different equipment. We chose a particular parameter (the "Length of P2" as shown in figure 4) which should be a constant value in a mature horse. This particular parameter was chosen for this test because it is not affected by how the hoof is trimmed, nor by the horse's stance at the moment the radiograph is taken. The variations observed in the measured values give an estimate of the repeatability of our method. The mean value measured was 4.96 cm with a minimum value of 4.88 cm and a maximum of 5.10 cm. Hence, all values are within 1.46 mm (or 2.94%) of the mean. We could also say that by these repeated measurements, we have determined the 95% confidence interval bounds on the mean value to be +/- 0.76 mm.

In the second test, we asked thirteen practitioners to make measurements following our technique *in the same image*. Since the same image was used by all practitioners, this test was designed to measure the repeatability of the technique as regards variations introduced by the practitioner following the procedure. For the purposes of this test, we looked at the repeatability of the parameters shown in figure 3, namely the coffin joint angle and the pastern joint angle. The mean value determined for the coffin joint angle was 14.70 degrees, with a minimum of 13.23 degrees and a maximum of 16.02 degrees. The mean value found for the pastern joint angle was 7.95 degrees, with a minimum of 6.45 degrees and a maximum of 9.90 degrees. Hence, all measured coffin-joint values were within 1.5 degrees of their means, and all measured pastern-joint angles were within 2.0 degree of their means. Combining all thirteen measurements results in a 95% confidence interval of +/- 0.50 degrees for the coffin-joint, and +/- 0.68 degrees for the pastern-joint.

Discussion

In a software implementation[a] of this technique, a total of 22 parameters are computed for the lateromedial radiograph. In the interest of keeping this paper to a reasonable length, of these 22 parameters, only 7 have been discussed and are shown in figures 1 through 4. In our repeatability tests, we only considered a few of these. It is likely that each of the parameters would be influenced somewhat differently by various sources of non-repeatability in measurement.

While we feel its important to have well-defined values for the various geometrical aspects of the hoof and bone, and our implementation has defined 22 parameters for the lateromedial radiograph, we do not intend that uniform importance should be accorded to all these measures. For example, in our opinion, most practitioners attach relatively too much significance to the values of the coffin-joint and pastern-joint angles. These measures are directly affected by how the horse is stood in preparation for taking the radiograph, and hence may not carry a great deal of information concerning the horse's true conformation. In our software implementation, the 22 parameters are divided into 3 categories: bone parameters, hoof parameters, and stance parameters. The 'bone parameters' should be unchanging in a mature horse, the 'stance parameters' are the joint angles, which depend on how the horse was stood for the radiograph. The 'hoof parameters' are the most interesting in that they are values which can be directly affected by trimming the hoof. Hence, they carry the most information concerning the portion of conformation over which the practitioner has some control.

In addition to this style of analysis of the lateromedial radiograph, we have similarly defined, and implemented in software, a technique for the horizontal dorsopalmar radiograph of the equine digit. In that case, a total of 16 parameters are defined. In a similar fashion, we have defined a measurement technique and associated sets of parameters for three photographic views of the hoof (lateral, frontal, solar).

More research is needed to determine what constitutes ideal conformation of the hoof and bones, as a function of the horse's breed, intended usage, and other factors. We hope that the research community will find the proposed method of defining conformation useful towards this goal.

References and Footnotes

1. Craig, J. *Introduction to Robotics: Mechanics and Control,* 2nd edition, Addison-Wesley, 1989.

2. Page B., Bowker R., Ovnicek G., et al. How to Mark the Foot for Radiography, in *Proceedings* 45th Annual AAEP Convention, Albuquerque, Dec. 1999; 148-150.

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