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Abstract

In obstetric science, it is unknown whether the inherent biomechanical features of the squatting position can be achieved and/or transposed to the supine birth position. In this study Biomechanical features of the squatting position were compared with 2 hyperflexed supine positions for giving birth. Thirteen pregnant women past the 32 weeks of gestational age not in labor were assessed first in the squatting position with the feet flat on the floor, then in the hyperflexed supine position, and finally in the optimal supine position "crushing" the hand of the caregiver onto the bed. For each position, the flexion of the spine associated with the plane of the external conjugate (*ANGce*) and the pelvis, hip flexion, and abduction were quantified using an optoelectronic motion capture system. A non-invasive strain-gauge-based measuring system was used to track the lumbar curve. An optimal position was defined with a flat lumbar spine and a pelvic inlet plane perpendicular to the lumbar spine (*ANGce*=0°±5°). For the 13 participants, hip flexion, hip abduction, and the lumbar curve did not differ significantly for the three positions (squatting position, hyperflexed supine position, and OS) in the post-hoc analyses. The optimal supine position induced an *ANGce* closer to the perpendicular plane than the squatting position (p=0.002). In the squatting position or in hyperflexed supine position positions, none of the subjects fulfilled the two conditions considered necessary to reach the optimal position.The squatting position was not significantly different from the supine hyperflexed supine position with or without voluntary lordosis correction.

Key Words: biomechanics, optimal birth position, squatting birth position, supine position

Introduction

In the 1800s, Engelmann observed that women not influenced by Western conventions mainly adopted the squatting position (SqP) during the first and second stages of labor (Engelmann, 1883). It is well known that, like other vertical positions during which the trunk is close to the vertical, the SqP has obstetrical advantages including reduced duration of the first and second stages of labor and a significant reduction in obstetrical interventions (Desseauve et al., 2017). Among the hypotheses that might explain these results, is that the vertical position, like the SqP is closest mechanically to the best birthing position. From a mechanical standpoint, an “optimal” birth position enables the axis of fetal progression to move perpendicularly to the superior pelvic inlet plane encountering the fewest obstacles by flattening the dorsal hinge (or kyphosis) and achieving a sort of “obstetric chute”(Desseauve et al., 2017a) as illustrated by Figure 1. This optimal condition is magnified particularly when the feet are flat on the floor, as we demonstrated in a recent biomechanical study (Desseauve et al., 2019a). The advantages of this position have been supported by studies in other fields. The SqP, in particular in hyperflexion, was the most favorable position to obtain a recto-anal canal close to rectitude during defecation, as lower abdominal pressure is necessary to facilitate defecation (Sakakibara et al., 2010). Even without direct comparisons, we could hypothesize that this position presents lower resistance to fetal progression.

Unfortunately, as for other vertical positions, SqP is rarely used because of the medicalization of childbirth in Western industrialized countries, and particularly in France (Desseauve et al., 2016), despite its obstetrical advantages. Positions frequently taken in the delivery room are widely influenced by constraints related to monitoring and medical interventions during labor and delivery (Spiby et al., 2003). Continuous fetal heart rate monitoring using cardiotocography, epidural anesthesia, and access to the woman’s perineum are some of the major factors favoring the horizontal position. Nevertheless, recent obstetrical solutions may allow pregnant women to stand and squat during labor. For example, the Women Health Organization has promoted intermittent fetal heart rate monitoring in low-risk pregnant women ("WHO | WHO recommendations," n.d.). However, it is not widespread due to the controversies surrounding fetal heart rate monitoring and the fear of potential litigation (Smith et al., 2012). Promoting mobility and alternative positions also involve the identification of new solutions in anesthesiology. Thus, low-dose combined spinal-epidural analgesia is an analgesic alternative compatible with the vertical position with benefits for delivery outcome (Bates et al., 1985). Fortunately, for the vast majority of low-risk childbirths, no assistance is required for successful outcomes of normal birth deliveries. The challenge of optimizing the birth position arises in cases of obstructed labor (Desseauve et al., 2017a). While waiting for the "popularization" of the vertical birth position, an intermediate solution could be to optimize the horizontal position in cases of difficult labors.

Current studies have highlighted the difficulty of correcting lordosis by flexion of the thighs, particularly in the supine birth position (Desseauve et al., 2019b). We have previously assumed the hypothesis that a better lordosis correction could be achieved through voluntary actions and guidance of the patient (Desseauve et al., 2019b).

The issue is thus to determine whether we can extrapolate the inherent biomechanical features of the vertical SqP to allow the easiest progression of the fetus through the birth canal by adopting a modified horizontal position. Intuitively, the supine birth position with a hyperflexion of the thighs seems to be similar to the SqP. The main objective of this study was to assess whether hyperflexion of the thighs, with or without the voluntary correction of the lumbar curve, could approximate the biomechanical features observed in the SqP with the feet lying flat.

Materials and methods

For this prospective comparative study, eligible participants were pregnant women aged>18 years and >32 weeks of gestation (third trimester), under physiological prenatal care, with a body mass index (BMI) <40 kg·m^{-2}, with no inflammatory joint disease or joint hypermobility syndrome, such as Marfan's syndrome.

The study protocol was approved by the Ethics Committee of Poitiers Hospital (Comité de Protection des Personnes: 2013-1203-42) and by the French National Agency of Drug Safety (Agence Nationale de Sécurité du Médicament: B131-460-22). All women provided written informed consent.

Based on the X-ray biomechanical study by Gherman et al (Gherman et al., 2000), we considered as significant a difference of 6° (5%) in the flexion of spine on the external conjugate's plane (this angle is discussed below as *FLEXs/ec*). Thus, we estimated 14 subjects were required to detect significant differences with a power of 90% and a risk of type I error of 5%.

A full protocol description about this innovative methodology is available (Desseauve et al., 2017b). A traditional three-dimensional motion analysis was performed to analyze the position of the markers. The analysis was based on an optoelectronic motion capture system consisting of 12 infrared cameras sampling at 100 Hz (VICON, Oxford Metrics, UK). Thirty-three reflective markers were fixed using double-sided tape on anatomical landmarks according to an adapted version of the Helen Hayes's marker set (Vaughan et al., 1999). We positioned additional marker clusters on the top of each iliac crest to assess the orientation of the pelvis. These marker clusters were projected to provide a technical coordinate system, allowing the reconstruction of the pelvic markers if they were be hidden during the experimentation. The position of the pelvic marker in this technical coordinate system could be defined during a static acquisition while standing.

The lumbar curve was assessed by measuring the lordosis obtained with the Epionics SqPINE system (Epionics Medical GmbH, Potsdam, Germany). This system sampling at 50 Hz consists of two flexible sensor strips that use strain gauge sensors located alongside flexible circuit board strips. The positioning of the system is standardized. Thus, a measured lordosis of 0° corresponds to a perfectly flattened back (D. Desseauve et al., 2017). The data was transmitted in real-time via Bluetooth to a local PC.

This biomechanical study took place in an experimental setting (i.e., not during labor). Women were first asked to assume the SqP with their feet flat on the floor. Next, we asked the subject to stand and then lie on a birthing bed (Maquet® Getinge AB, Göteborg, Sweden) with an angle of inclination of the headboard of 30°. Subjects were positioned in the gynecological position (i.e. lying on the back with the hip flexed at 90 degrees, the legs being supported by padded foot rests attached to the table), with maximal flexion and abduction of the hips (*HSuP position*). After data acquisition in this posture, the investigator's hand was placed under the residual lumbar curve and the subject was asked to "crush" the hand onto the bed (Figure 2). Subsequently, the hand was removed and further data acquisition was performed. This position is further referred to as H+CSuP. For all three positions, data acquisition was performed when the subject was stabilized for at least three seconds.

A custom Matlab code (MathWorks Inc., Natick, MA) was used to merge data from the Epionics and VICON systems and to extract the required data.

Marker trajectories were low-pass filtered using a double-pass Butterworth filter with a cutoff frequency of 10 Hz. The hip flexion and abduction were obtained as defined by the conventional gait model (Kadaba et al., 1989). For the HSuP and H+CSuP positions, the markers located on the posterosuperior iliac spines required to obtain pelvis and hip angles were hidden in the supine position. Hence, their locations in the aforementioned technical referential frames were established using a static standing position. Additionally, the same method was used for the markers placed on vertebrae C7 and T10, which were also occulted in the supine position. In this case, the technical referential frame was defined with reflective markers placed on the thorax.

We defined a plane containing the external conjugate diameter using two markers located on the postero-superior iliac spines and a marker located on the superior edge of the pubic symphysis. The flexion of the external conjugate's plane on the spine (*FLEXs/ec*) was computed in the sagittal plane as the angle between the external conjugate's and the line passing through the reconstructed markers located on the level of vertebrae C7 and T10 (Figure 3). The lumbar curvature was measured for the three different positions for each subject.

From a theoretical standpoint, as depicted in Figure 1, an "optimal" birth position enables the axis of progression to move perpendicularly to the superior pelvic inlet plane encountering the fewest obstacles by flattening the dorsal hinge (or kyphosis). For each woman, conditions for optimal birth were then assessed by considering the *FLEXs/ec* and lumbar lordosis values. As proposed in a previous study, the pelvic inlet plane was considered optimal when almost perpendicular to the spine, namely when *FLEXs/ec* reached ±5° (taking into account the precision of the measurements). We considered that the back was flat at -3° of lumbar lordosis or in kyphosis, which corresponded to positive values of the lumbar curve measurement (Desseauve et al., 2019a).

We used non-parametric variance analysis (i.e. the Friedman test) to compare all values obtained (hip flexion, hip abduction, lumbar curves, *FLEXs/ec*) for the three different positions, since the data were repeated measures and not normally distributed. If significant differences were observed, a post-hoc analysis was performed using the Wilcoxon matchedpairs signed-ranks test, with a *Bonferroni* correction to compare the conditions two-by-two (Bender and Lange, 2001). For the *Bonferroni* correction, the cut-off for significance for p-values was based on that obtained by the Wilcoxon test and was divided by the number of post-hoc tests needed to compare conditions two-by-two. In this study, three tests were needed.

Results

Overall, 14 participants were assessed, with no withdrawals during the study. The data for one participant could not be interpreted due to an error of data transmission from the Epionics SqPINE System. The mean age of the participants was 32.8 (SD 2.8) years, and the mean gestational age at inclusion was 34.0 (SD 0.7) weeks. The mean BMI was 26.0 (SD 0.8) $kg \cdot m^{-2}$. Seven participants (60%) were primiparous.

The measured values for the lumbar curve and *FLEXs/ec* for each position for each subject are summarized in *Table* 1, whereas *Table 2* presents the results of the statistical tests.

Hip flexion and the lumbar curve were not significantly different between the three positions: SqP, HSuP, and H+CSuP (*Table* 2), while the *FLEXs/ec* and hip abduction differed. However, when the values were compared in the post-hoc analysis, the values of hip abduction in the SqP, HSuP, and H+CSuP positions were not significantly different for the three positions (*Table 2*). Regarding the *FLEXs/ec*, the H+CSuP achieved an angle of the pelvic inlet plane closer to a position perpendicular to the spine axis than the SqP (p=0.002, significant also after *Bonferroni* correction).

Considering optimal conditions, none of the women fulfilled the two conditions assumed to be necessary to obtain the hypothesized optimal position in the SqP or HSuP (*Table 1*) and only subject 9 achieved optimal conditions in the H+CSuP position. Indeed, this subject was the only one having a pelvic inlet plane perpendicular to the spine (*FLEXs/ec*=0°±5°) in the H+CSuP position. A flat back or kyphosis was obtained for 9 subjects in SqP, 10 subjects in HSuP and all the subjects (N=13) in H+CSuP (*Table 1*).

Discussion

The supine positions with hip hyperflexion were similar in terms of pelvic orientation and lordosis than SqP with flat feet. Regarding optimal conditions, the supine positions with hip hyperflexion were more prone to induce a correct lumbar curve. Asking the subject to “crush” the hand onto the bed to correct an eventual residual lordosis was particularly successful since no lordosis was measured afterwards. In all positions, the pelvic inlet plane failed to be perpendicular to the spine for all subjects except one.

The quest to find an optimal birth position is a challenge in the obstetrics field, particularly for cases of obstructed labor. In this context, women are usually placed in the supine position, requiring cardiotocography, analgesics, and obstetric care providers to determine the most favorable position. Because the advantages of vertical positions have been described in several meta-analysis (Gupta et al., 2017; Kibuka and Thornton, 2017; Lawrence et al., 2013), our goal in the present study was to obtain a modified supine position presenting biomechanical features of the vertical position to be used in case of obstructed labor (David Desseauve et al., 2017a). We acknowledge that the results of the recent BUMPES (Birth in the Upright Maternal Position with Epidural in Second stage) clinical trial (Epidural and Position Trial Collaborative Group, 2017) counteract previous findings on the advantages of the vertical position in the second stage of labor, with no differences in maternal obstetrical or fetal outcomes. However, the BUMPS trial, like other interventional studies (Epidural and Position Trial Collaborative Group, 2017; Guittier et al., 2016; Le Ray et al., 2016), failed to define the best birthing position due to a rough definition of the position, specifically neglecting the biomechanical features of each birth position (Desseauve et al., 2017a).

SqP is a unique position naturally assumed by women in non-Western countries (Engelmann, 1883).By definition, as opposed to the standing position, the SqP refers to a posture in which the knees are flexed. This flexion results in a distancing of the legs and thighs relative to the vertical. This particular mobilization of the lower limbs leads to the forward inclination of the trunk, made possible by displacing the center of gravity in the support polygon. By limiting muscle activation of the quadriceps muscles, the glutes lean on the calves, making this posture as comfortable as possible. In addition, a recent study also demonstrated that squatting with the feet flat on the ground is closer to optimal birth conditions than standing on tiptoes (Desseauve et al., 2019a).

According to the present study, the biomechanical properties of SqP with the feet flat can be "achieved lying on the back" with hip hyperflexion. Nevertheless, lying on the back, the potential beneficial effects of gravity are lost. This deficit in gravity could compromise the efficiency of the back-lying position, particularly for the optimal position proposed in this study. However the impact of gravity remains a topic of discussion. In a previous study, we determined the role of gravity during childbirth and, in accordance with the results of Ashton-Miller et al, the force applied to the fetus due to gravity during labor is not negligible, but is considerably lower than forces caused by uterine contractions during pushing (19N versus 120N, respectively) (Ashton-Miller and Delancey, 2009; Desseauve et al., 2017a). Thus, our optimal position could be proposed for women experiencing obstructed labor once these preliminary results are confirmed by additional studies.

It is important to note that the conditions for an optimal position were not achieved by our subjects in the SqP. In the hyperflexed gynecological position, all subjects remained quite far from the optimal conditions for the pelvis. In the hyperflexed position with correction of the lumbar curve, the angle between the upper strait and the lumbar spine was greater than 90° for the majority of subjects, while no lumbar lordosis was observed. Thus, placing the hand behind the subject's back, giving instructions to try to "crush" the hand, and removing the hand would correct the lumbar lordosis. In preliminary studies, we had attempted to give subjects only instructions to round the back, and subjects tended to basically raise their shoulders, which did not necessarily result in the correction of the lumbar lordosis. The instruction to crush the hand, which is relatively easy to place beneath the woman's back, is therefore sufficient is therefore sufficient even if the hand is after that removed. The fact that the lumbar curvature deviates from the neutral value corresponding to a "flat back" to a positive value, i.e. to a "round back" following this instruction, was not problematic according to the obstetrical slide that we defined in a previous study (Desseauve et al., 2019 a,b). The increasing lumbar kyphosis was not problematic even for subjects in whom kyphosis was close to or >10° (subjects 3, 6, 9 and 13). Beyond a flat back, it may also be necessary to "round" the back in order to achieve an optimal position of the pelvis, which was achieved only in subject 9 who obtained the most important kyphosis in our study sample. In practice, it is quite easy to correct a hollow back to a flat back by asking the subject to "crush" the midwife's hand placed beneath the subject's back. In future studies, if it is demonstrated that obtaining a round back (in kyphosis) is required to achieve an optimal position, we should pursue this new technological challenge, as there are currently no labor beds designed to support the parturient in this position. Kyphosis could be difficult to achieve during obstetrical labor with subjects only "wedged" between cushions, for example.

We believe that this is the first observational study comparing biomechanical features of SqP and lying positions with hip hyperflexion. Its aim was to define a better position for giving birth with the objective of helping women and care providers in cases of an obstructed labor and a lying position is required. The major strength of our analysis was the assessment of the pelvic position and lordosis using a motion analysis system that could be introduced in the labor room. Previous studies have assessed the birth position using magnetic resonance imaging, but with no formal definitions or control of the position, and with the aim of measuring variations in pelvic dimension (Michel et al., 2002; Reitter et al., 2014).

A further limitation involved the voluntary impulse to flatten the back during the assessment of the biomechanical effects. These actions involved muscular activation that could have a specific biomechanical impact on the position and movement of pelvic bones due to the contraction of the rectus abdominis for example. Future studies should thus explore differences between actively and passively achieving a certain position to identify the impact of activation of the abdominal muscles. It may be quite difficult to mobilize women during labor; however, it could be possible to flatten the lumbar spine, by slipping the woman's buttock towards the edge of the birth table when the thighs are hyperflexed, resulting in the nutation of the pelvis (de Gasquet, 2009).

The optimal position according to our definition was achieved only in one patient. All patients included in this study gave birth naturally with no obstetrical intervention (i.e. assisted delivery, or caesarean section). Our optimal criteria were likely too restrictive. It is probably not a perfect pelvic position defined by physics law that is required, but rather a threshold to be reached in terms of the angle between the pelvic inlet plane and the lumbar spine. This threshold angle remains to be defined in a future "in labor" live studies.

A major limitation to this pilot study was it was performed using women in their third trimester near term, but not in labor. Our results should be confirmed during labor. A randomized control trial during the second stage of labor comparing the supine position and the hyperflexed "after crushing" position that we defined in the present study could be a further step to confirm the impact of positions on obstetrical outcomes (labor duration, caesarean section, duration of the second phase of labor). Thereby the advantages of our motion capture system are associated with further limitation as our methodology could not assess the size of the pelvic inlet or the dimensions of the pelvis outlet. The notion that the thigh position affects the pelvis size dates to back to 1969, when Russell reported, "if the thighs are flexed and abducted the femora act as lever on the innominate bones to open the bony outlet" (Russell, 1969). A comparison of the pelvic size according to the three positions assessed in our study would have enhanced our results. Nevertheless, the change in pelvic size is tenuous and limited to millimeters, thus the potential effect of additional abduction would likely be minimal (Gherman et al., 2000).

The necessity to consider pelvic disorders induced by the evolution of the human species to predict and interpret research outcomes in obstructed labor has stimulated new research (Pavličev et al., 2019). Neglecting the pelvic dimension in our study avoids the assessment and characterization of pelvic disorders. Ongoing research (Leenaards fondation 2019, n.d.) should provide statistical shape models that could be used to more accurately estimate the position and the orientation of the pelvic inlet plane based on the position of the bony surface.

Conclusion

When the supine position is required, hyperflexion of the thighs may approximate the biomechanical features observed in squatting position births with the feet flat. Of all positions, the hyperflexed position with a lordosis correction had a spine the closest to the perpendicular to the superior pelvic inlet plane. However, neither the squatting position nor this proposed hyperflexed position after lordosis correction achieved the optimal mechanical conditions hypothesized for giving birth.

Conflict of interest statement

The authors report no conflicts of interest.

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TABLES

Table 1: Values of the flexion of the plane of the external conjugate on the spine (*FLEXs/ec*), and lumbar curve for each subject according to the three birth positions assessed: squatting position with feet flat (SqP), hyperflexed supine position (HSuP), and hyperflexed supine position with lordosis correction (H+CSuP).

	FLEXs/ec (°)			Lumbar curve (°)		
Subject	**SqP**	**HSuP**	**H+CSuP**	**SqP**	**HSuP**	**H+CSuP**
1	-32.4	-29.4	-21.7	-20.7	-0.2*	6.9*
2	-50.1	-29.5	-21.4	-28.1	0.5*	8.6*
3	-38.8	-29.9	-16.9	0.5*	-0.6*	9.5*
4	-37.4	-33.7	-26.2	-4.3	-4.8	6.6*
5	-33.3	-32	-26.3	-0.6*	-0.3*	5.9*
6	-30.5	-29.8	-19.8	-7	-5.5	9.9*
7	-21.8	-27.7	-28	13.5*	-2.3*	3.2*
8	-44.5	-30.6	-28.3	0.3*	-0.4*	1.2*
9	-44.3	-31.4	-1.3*	12.4*	-1.7*	27.4*
10	-35.1	-30.6	-25	7.6*	0.3*	4.8*
11	-35.1	-35.8	-24.1	1*	-6.3	1.6*
12	-18.6	-23.3	-24.6	1.4*	5*	2.7*
13	-25.7	-27.3	-13.6	8.4*	2.4*	15.1*

*Note: *: values of optimal lumbar curvature or FLEXs/ec.*

Table 2: Average values tested in the study (mean, SD), and post-hoc analysis results for the parameters of the pelvis *(FLEXs/ec*: flexion on the spine related to the plane of the pelvis external conjugate), lumbar curve, and thighs (hip flexion, hips abduction), according to the three positions assessed: squatting position with feet flat (SqP), hyperflexed position (HSuP), and hyperflexed supine position with lordosis correction (H+CSuP).

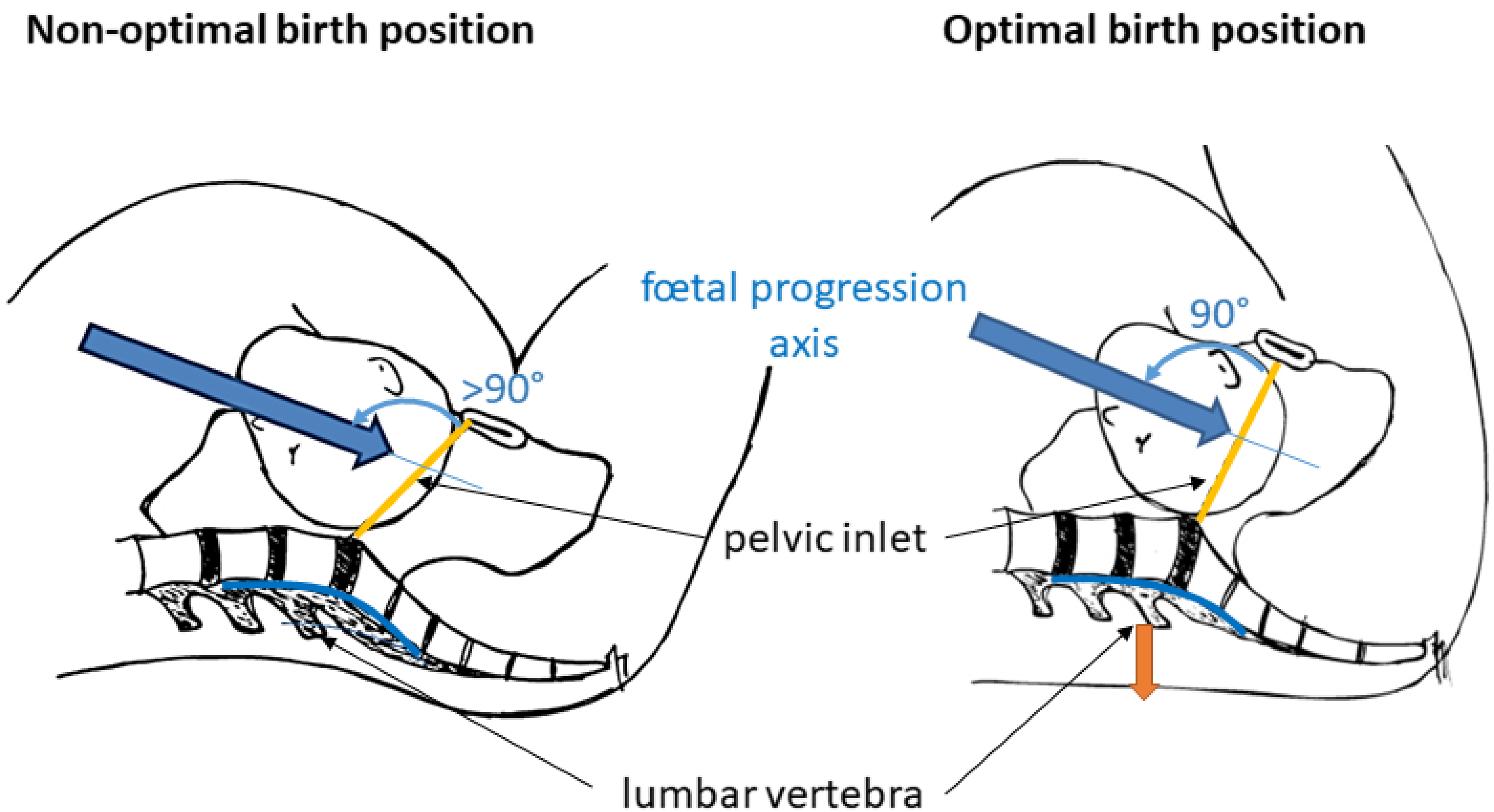
	SqP	**HSuP**	**H+CSuP**		***Post Hoc analysis results***			
	$\overline{X}$ **[SD]**	$\overline{X}$ **[SD]**	$\overline{X}$ **[SD]**	**Friedman's p value**	**Bonferroni's significant p-value**	**SqP/HSuP**	**SqP/H+CSuP**	**HSuP/H+CSuP**
Hip Flexion (°)	125 [15]	118 [12]	116 [10]	0.17	-	0.14	0.06	0.1
Hip Abduction (°)	28 [10]	44 [6]	44 [7]	$<10^{-5}$	$<10^{-5}$	0.001	0.002	0.17
FLEXs/ec (°)	-34 [9]	-22 [7]	-21 [7]	<0.001	0.002	0.003	0.002	0.28
Lumbar curve (°)	-1 [12]	-1 [3]	0 [3]	0.3	-	0.63	0.70	0.14

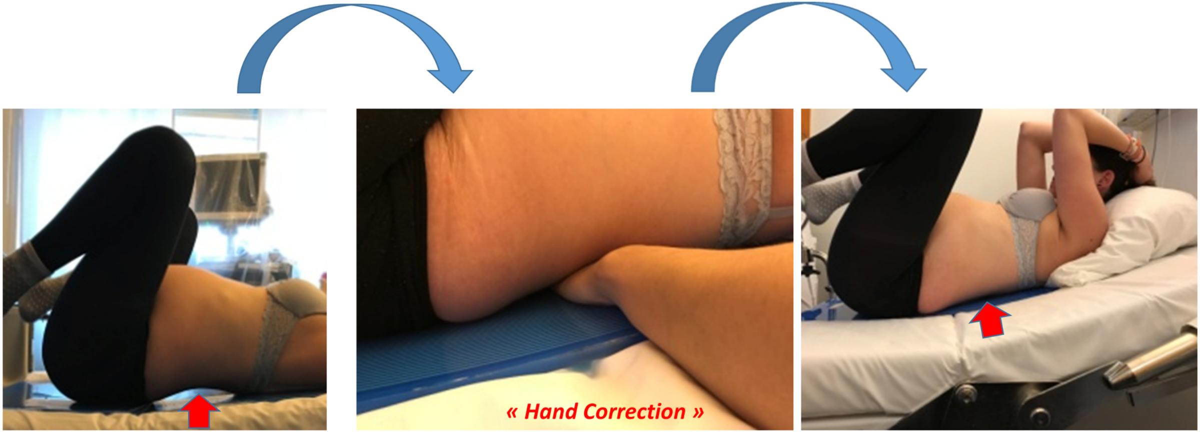
Figure Legends

Figure 1: Illustration of the optimal birth conditions

Figure 2: Illustration of the investigator's hand correction to obtain a hyperflexed supine position with lumbar correction (H+CSuP), from a hyperflexed supine position (HSuP)

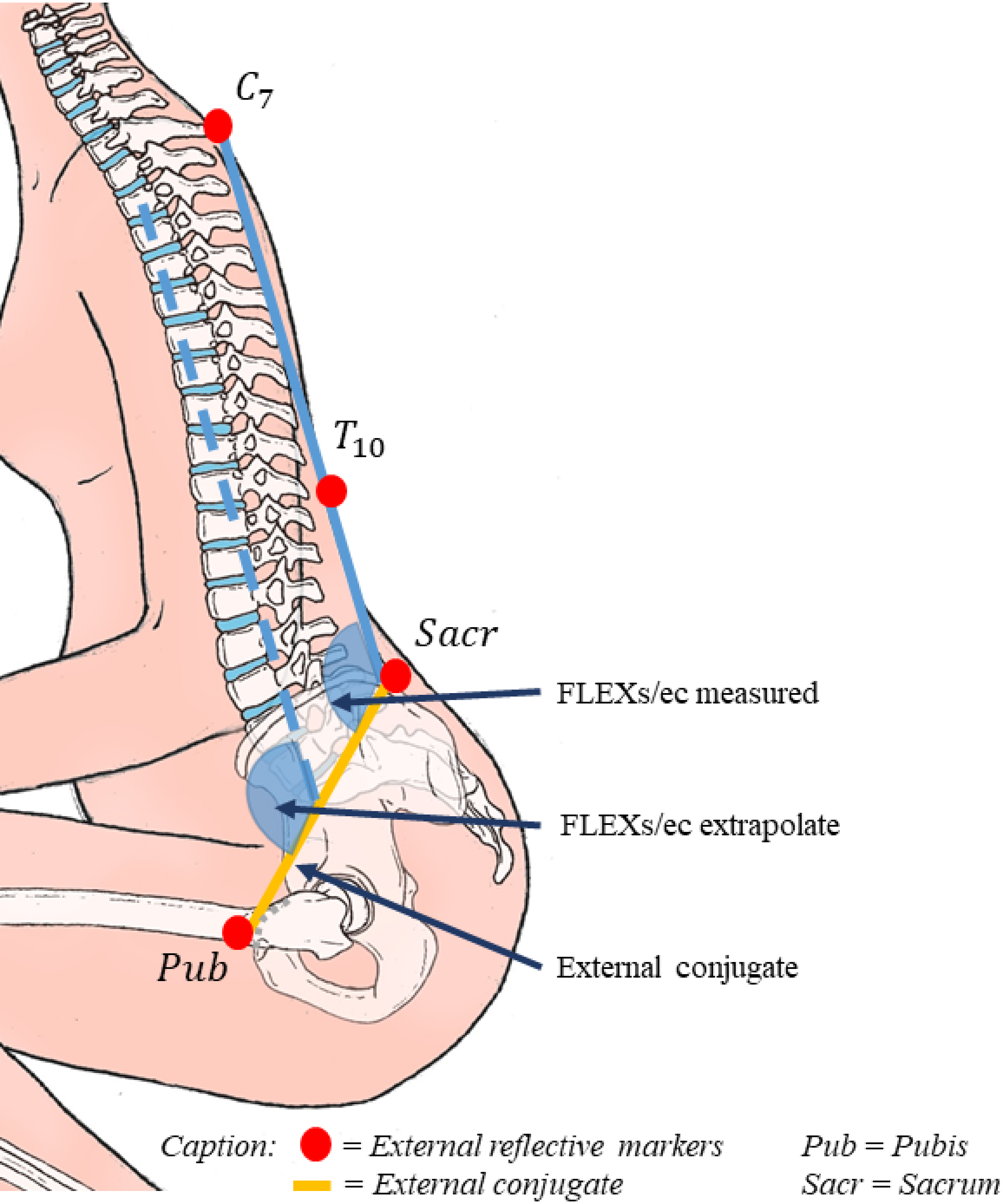
Figure 3: Definition of *FLEXs/ec* and external conjugate


Non-optimal birth position
Optimal birth position
fœtal progression
axis
>90°
90°
pelvic inlet
lumbar vertebra



Hyperflexed Supine position (HS)

Optimal Supine position (OS)



C_7
T_{10}
$Sacr$
FLEXs/ec measured
FLEXs/ec extrapolate
External conjugate
Pub
Caption: = External reflective markers
= External conjugate
Pub = Pubis
Sacr = Sacrum