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Anterior subcutaneous internal fixation of the pelvis – what rod-to-bone distance is anatomically optimal?

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1 **Abstract**

2 **Introduction** Anterior fixation of the pelvis using subcutaneous supra-acetabular
3 pedicle screw internal fixation (INFIX) has proven to be a useful tool by avoiding the
4 downsides of external fixation in patients where open fixation is not suited.

5 The purpose of this study was to find a rod-to-bone distance for the INFIX that allows
6 for minimal hazard to the inguinal neuro-vascular structures and, at the same time, as
7 little as possible interference with the soft tissues of the proximal thigh when the
8 patient is sitting.

9 **Methods** An INFIX was applied to 10 soft-embalmed cadaver pelvises with three
10 different rod-to-bone distances. With each configuration, the relations of the rod to the
11 neuro-vascular and the muscular surroundings were measured in supine and sitting
12 position.

13 **Results** Except for the femoral artery, vein and nerve, all investigated anatomical
14 structures of the groin were under compression with a rod-to-bone distance of 1 cm.
15 With a rod-to-bone distance of 2 cm most of the anatomical structures were safe in
16 supine position, although less than with 3 cm. With hip flexion some structures got
17 under compression, especially the lateral femoral cutaneous nerve (LFCN, 80 %) and
18 the anterior cutaneous branches of the femoral nerve (ACBFN, 35 %). With a rod-to-
19 bone distance of 3 cm almost all anatomical structures were safe in supine position,
20 while with hip flexion most superficial structures of the proximal thigh got under
21 compression, especially the LFCN (75 %) and the ACBFN (60 %).

22 **Conclusions** Aiming for a rod-to-bone distance of 2 cm is the safest way with regard
23 to compression of the femoral neuro-vascular bundle and at the same time leads to the

1 least compression of more superficial structures like the LFCN, the ACBFN, or the
2 sartorius and the rectus femoris muscles in sitting position.

3

4 **Keywords:** pelvic fracture; sacral fracture; INFIX; subcutaneous internal fixation;
5 pelvis; elderly.

6

7 **Level of Evidence:** Basic Science Study

1 **Introduction**

2 External fixation has been an established technique for the immediate stabilization of
3 pelvic ring injuries ^{1,2}.

4 However, it usually serves only as a temporary stabilization, rolling the patient side-
5 to-side and sitting are limited, and its use is associated with pin tract infections in up
6 to 50 % of cases ³.

7 Anterior fixation of the pelvis using supra-acetabular pedicle screw internal fixation
8 (INFIX) has proven to be a useful tool in certain situations by avoiding the downsides
9 of external fixation in patients where open fixation is not suited ⁴⁻⁶. In the authors'
10 experience, the INFIX has been noted to be disturbing for patients when sitting if
11 applied with too much distance from the bone. Other case series pointed out the
12 potential risks associated with placing the rod too close to the bone but also described
13 implant impingement, especially in thin patients ⁷⁻⁹. Several important neuro-vascular
14 structures are in close vicinity to the connecting rod of this device (Figure 1) and
15 could be injured or compressed with a too small rod-to-bone distance. The femoral
16 artery and vein and the femoral nerve are both running underneath the rod and clinical
17 series have shown an irritation of the lateral cutaneous nerve in up to 27 % of the
18 cases ¹⁰⁻¹². Interference of the rod and the supra-acetabular pedicle screws with the
19 muscles of the proximal thigh in hip flexion has been noted in some patients and
20 could - together with the typical location of the screws - be an explanation for the
21 occurrence of heterotopic ossifications in up to 32 % of the cases ¹⁰⁻¹².

22 While there exist studies investigating the anatomical relations of the rod and the
23 pedicle screws to their surroundings in general ¹³⁻¹⁵, no study has quantified these
24 relations particular in view of different rod-to-bone distances, so far. Therefore, the

1 purpose of this study was to find a rod-to-bone distance in anterior subcutaneous
2 internal fixation of the pelvis that allows for minimal hazard to the neuro-vascular and
3 as little as possible interference with the muscular surroundings of the inguinal area.
4 It was our hypothesis that a rod-to-bone distance too small will put the femoral
5 vessels and the femoral nerve under continuous compression in any position, while
6 with a rod-to-bone distance too large, the rod and pedicle screws will interfere with
7 the ilio-psoas muscle in sitting position.

8
9

10 **Material and Methods**

This study was conducted in accordance with the local laws for body donations and
the rules of the institutional donation program

11 *Specimens*

12 Ten cadavers of different size and age (female: 3; all Caucasian; mean donor age: 82
13 years, range 55 to 100 years; height: 172 cm, range 153 to 180 cm; weight: 76 kg,
14 range 50 to 95 kg) with 20 groins were used for this study. All cadavers had
15 undergone soft-embalmmment as described by Thiel ¹⁶. The advantage of embalmmment
16 with Thiel's solution is the ability of this technique to preserve the tissues' color,
17 consistency, and transparency to a high degree without the risk of decomposition ¹⁷.
18 The INFIX was then applied percutaneously through two small supraacetabular
19 incisions of 2 cm length as previously described ⁴⁻⁶. An 8.0 mm-pedicle screw of 80
20 mm length was placed bilaterally into the supraacetabular osseous canal at the level of
21 the anterior inferior iliac spine (AIIS). Both screws were connected by a 5.5 mm-rod

1 that was inserted subcutaneously anterior to the symphysis (VIPER, Sacro-Alar-Iliac
2 Fixation system, DePuySynthes, Zuchwil, Switzerland). The rod was pre-bent before
3 attachment into the screw heads and fixed with its curvature in the plane of the screw
4 shafts (Figure 1).

5 The skin was then removed from the inguinal region and the anatomic assessments
6 and pressure measurements were performed as described below. Care was taken to
7 remove as little surrounding soft tissues as possible.

8 The INFIX pedicle screws were consecutively inserted with different rod-to-bone
9 distances at the level of the supra-acetabular pedicle screw of 1 cm, 2 cm, and 3. With
10 each configuration, the relation of the rod to the neuro-vascular and the muscular
11 surroundings will be described and measured, once in supine and once in sitting
12 position of the cadaver. The changes in compartmental pressure inside the muscular
13 and the vascular lacunae were measured with both positions.

14 Each groin measured separately.

15

16 *Anatomical measurements*

17 After skin removal, the shortest anatomical distances between the implant rod and the
18 femoral artery, vein and nerve, the lateral femoral cutaneous nerve (LFCN), the
19 anterior cutaneous branches of the femoral nerve (ACBFN), and the sartorius and
20 rectus femoris muscle were measured by the use of a vernier calliper (Helios Preisser,
21 Gammertingen, Germany) by the same person. These measurements were done on
22 each side once in supine (hip extended to 0°) and once in sitting position (hip flexed
23 to 90°) and repeated for each of the three rod-to-bone distances. In addition, the
24 distance between the screw shafts and the LFCN, the sartorius muscle and the rectus

1 femoris muscle were measured in supine position. All measurements were performed
2 by one of the authors (JS) who had practiced and standardized the measurement
3 technique during preliminary tests on two other cadavers. During these preliminary
4 experiments, it was evaluated whether there were relevant differences between sitting
5 and hip flexion in supine position for the observed anatomical distances in the
6 inguinal area. In the two cadavers for preliminary testing, the differences for the
7 distances between rod and femoral neurovascular bundle showed to be less than 2 mm
8 when comparing real sitting to just flexing the hip.

9

10 *Pressure measurements*

11 For pressure measurements, balloon tamps connected to a manometric device from a
12 kyphoplasty system (KyphX-Systems, Kyphon, Medtronic, Fridley, MN, USA) were
13 introduced into the *Lacuna vasorum* and *Lacuna musculorum*. The pressure
14 measurements were performed before skin removal in the inguinal area. The
15 abdominal wall was opened cranial to the inguinal ligament without opening of the
16 peritoneal cavity. First, the *Lacuna vasorum* was carefully dissected digitally in distal
17 direction and the balloon was positioned under sight into the subinguinal fossa (Figure
18 2). The differences in balloon pressure in supine and in sitting position of the cadaver
19 were documented. the same procedure was then repeated for the *Lacuna musulorum*.

20

21 *Descriptive anatomy*

22 In addition to the quantitative measurements, the anatomical relations of the screw
23 and the rod in context to the surrounding anatomical structures and layers were
24 described (e.g. the spermatic cord, presence of inguinal hernias, etc.).

1

2 *Statistical analysis*

3 Statistical analysis was done by the use of SPSS for windows 22.0 (SPSS, Chicago,
4 Illinois, USA). Metric data was processed using a One-Way ANOVA with Bonferroni
5 corrections for comparisons of anatomical and pressure measurements between the
6 three rod-to-bone distances. Differences were considered significant for values of $p <$
7 0.05. Results are presented as mean and standard deviation (SD).

8

9 **Results**

10 *Anatomical measurements*

11 Absolute distances between the implant rod and anatomical structures are listed in
12 Table 1.

13 In supine position with the hips extended, an increase of the rod-to-bone distance was
14 associated with also an increase of the distances between the rod and the anatomical
15 structures of the groin. With the hips flexed, however, increasing the rod-to-bone
16 distance lead to more compression due to the progressive protrusion of the INFIX into
17 the soft tissues of the proximal thigh.

18 In order to better account for the cadavers' differences in size and physique, rather
19 than comparing absolute measurements, we calculated the percentages of groins
20 where the measured anatomical structure was in vicinity of less than 3 mm to the
21 implant rod (Figure 3). A distance of less than 3 mm was thought to represent an
22 increased risk for compression of the respective anatomical structure as often small
23 amounts of surrounding fat had to be removed to dissect the nerves and vessels.

1 Except for the femoral artery, vein and nerve, all investigated anatomical structures of
2 the groin were under compression with a rod-to-bone distance of 1 cm in supine
3 position (Figure 4 A). In sitting position with the hip flexed, even the femoral artery,
4 vein and nerve were in close vicinity to the implants in some samples.

5 With a rod-to-bone distance of 2 cm most of the anatomical structures were safe in
6 supine position (Figure 4 B), although less than with 3 cm. With hip flexion some
7 structures got under compression, especially the LFCN (80 %) and the ACBFN (35
8 %).

9 With a rod-to-bone distance of 3 cm almost all anatomical structures were safe in
10 supine position (Figure 4 C), while with hip flexion most superficial structures of the
11 proximal thigh got under compression, especially the LFCN (75 %) and the ACBFN
12 (60 %).

13 The sartorius muscle was compressed in almost all of the samples, especially when
14 the hips were flexed or in supine position when the rod-to-bone distance was 1 cm.

15 The rectus femoris muscle was only very rarely compressed in both positions and only
16 with a rod-to-bone distance of 1 cm.

17 However, 80 % (4/20) of the screws perforated the sartorius muscle and all screws
18 (20/20) perforated the rectus femoris muscle or at least its tendon's origin. If not
19 perforated by a screw, the sartorius muscle was always at least touching it. Seven
20 screws (35 %) were in close vicinity (less than 3 mm) to the LFCN.

21

22 *Pressure measurements*

23 The change of pressure with sitting was calculated by subtracting the pressure
24 measured in supine position from the pressure measured in sitting position.

1 In the *Lacuna vasorum*, the balloon pressure when sitting up increased by 107 mbar
2 (SD 76 mbar) with a rod-to-bone distance of 1 cm, by 38 mbar (SD 52 mbar) with 2
3 cm, and by 21 mbar (SD 51 mbar) with 3 cm.

4 In the *Lacuna musculorum*, the balloon pressure when sitting up increased by 152
5 mbar (SD 124 mbar) with a rod-to-bone distance of 1 cm, by 52 mbar (SD 67 mbar)
6 with 2 cm, and by 31 mbar (SD 42 mbar) with 3 cm.

7 In both compartments, there was a significantly smaller increase of balloon pressure
8 when sitting up with an INFIX applied in 1 cm rod-to-bone distance when compared
9 to the configurations with 2 or 3 cm (Figure 5).

10

11 *Descriptive anatomy*

12 Even though in close anatomical proximity, the rod did not injure the spermatic cord
13 in any of the male cadavers (Figure 6 A). The skinnier the cadaver, however, the
14 closer to the spermatic cord the rod had to be placed subcutaneously.

15 Especially in skinny patients, the rod protruded more prominently the greater the rod-
16 to-bone distance was. With a rod-to-bone distance of 3 cm, this lead to noticeable
17 tenting of the skin in non-obese patients.

18 Two cadavers had right-sided inguinal hernias, that again both were not injured by the
19 rod but were in close anatomical vicinity to it (Figure 6 B).

20 As the LFCN often ran laterally to the screws it was sometimes only compressed by
21 the part of the rod jutting out the screw head laterally (Figure 6 C). In these cases,
22 compression of the nerve could have been avoided by choosing a shorter rod with less
23 overlap.

- 1 While it was unavoidable to perforate the rectus femoris muscle or at least its tendon
- 2 when placing screws into the supraacetabular bone, it was often possible to palpate
- 3 the sartorius muscle after the skin incision was made and then to insert the screw just
- 4 next to the muscle.

1 **Discussion**

2 The purpose of this study was to find a rod-to-bone distance in anterior subcutaneous
3 internal fixation of the pelvis that allows for minimal hazard to the neuro-vascular and
4 as little as possible interference with the muscular surroundings of the inguinal area.

5 As it was our hypothesis, we observed more compression of the anatomical structures
6 of the groin with a rod-to-bone distance too small (i.e. 1 cm) in any position and
7 increased compression due to the progressive protrusion of the INFIX with a rod-to-
8 bone distance too large (i.e. 3 cm). In line with these topographic findings, we
9 observed significantly higher balloon pressure changes in the vascular and muscular
10 *lacunae* of the groin when the rod-to-bone distance was too small.

11 With the three distances investigated in this study, it seems that an INFIX with a rod-
12 to-bone distance of 2 cm is associated with the least compression of inguinal
13 structures in both sitting and supine position.

14 Even with a rod-to-bone distance of 1 cm the greater neuro-vascular structures
15 (femoral n., a., v.) were never close proximity to the rod in supine position and only
16 very rarely in sitting position. In their anatomical study based on CT scans in supine
17 position of 13 patients with an INFIX, Merriman et al.¹⁵ observed an average distance
18 from the vascular bundle to the connecting rod of 2.2 cm. This is more than our
19 results for a rod-to-bone distance of 1 cm and less than our results a rod-to-bone
20 distance of 2 cm and, thus, consistent with their reported “screw out bone” distance of
21 1.8 cm. A recent anatomical dissection study by Apivatthakakul and Rujiwattanapong
22¹³ found average distances between rod and femoral nerve (12.5 mm), femoral artery
23 (12.8 mm) and femoral vein (13.5 mm) that were very close to the measurements of

1 this study, but the authors did not differentiate their results for different rod-to-bone
2 distances.

3 Neither Merriman et al. nor any of the other clinical INFIX cohort studies reported
4 problems with femoral vascular compression ^{4, 8, 10-12}. Although the surgeon must keep
5 these structures in mind when inserting the rod subcutaneously, it seems that
6 compression of the femoral neuro-vascular bundle is less of a concern once the INFIX
7 is applied with a rod-to-bone distance of about 2 cm.

8 Clinical studies rather point to the fact that stabilization of pelvic ring injuries with an
9 INFIX is often associated with postoperative irritation of the LFCN in up to 27 % of
10 the cases ^{8, 10-12}. In the authors' own experience, the patients often experience pain in
11 the anterior region of the thigh when sitting. All these complaints are well explained
12 by the compression of the ACBFN and the LFCN seen in sitting position of the
13 cadavers in our study. Even though not a major complication, pain and paraesthesia in
14 the thighs are frequently the reason why patients ask for early removal of the INFIX.
15 It seems that a rod-to-bone of 2 cm (less compression of the ACBFN when sitting)
16 and a rod with as little lateral overlap as possible (less avoidable affection of the
17 LFCN) might help to reduce the rate of these complications.

18 It remains unclear whether the high occurrence of heterotopic ossifications in up to a
19 third of the patients ¹⁰⁻¹² is rather related to the direct injury of the screws perforating
20 the rectus femoris and the sartorius muscle or to compression by rod. If rod
21 compression is the problem, a rod-to-bone distance of 2 cm would again be
22 favourable. If it is the direct injury from the screws, the surgeon would be advised to
23 palpate and spare the sartorius muscle when placing the screws.

1 A common limitation of morphometric cadaver studies is the often relatively small
2 sample size due to the limited availability of cadavers. This makes the results
3 vulnerable for confounding factors like donor height and weight or individual
4 anatomic variability. In addition, removing the skin and some of the superficial soft
5 tissues to allow for direct anatomical measurements may have changed the pattern of
6 evasion or deflection of vessels and nerves when being affected by the rod or flexion
7 of the hip.

8 The alternative would have been to do morphometric measures based on 3D imaging
9 like CT or MRI scans in a large number of real patients with an INFIX¹⁵. The
10 advantage of a cadaver study, however, is the fact that different rod-to-bone distances
11 can be compared in the same body. This would not be possible in real patients.

12 Using soft-embalmed cadavers¹⁶ with a consistency very similar to the living
13 anatomy we were able to observe dynamic changes which would have been very
14 difficult when using 3D imaging. The same accounts for pressure measurements in the
15 vascular and muscular *lacunae*, although it has to be clear that the absolute
16 measurements of balloon pressure do not represent the intracompartmental pressures
17 in a living person. Yet, the changes in balloon pressure should provide an indication
18 of the different pressure patterns under different external conditions like compression
19 by an INFIX rod.

20 For this study, rod-to-bone distances of 1 cm, 2 cm, and 3 cm were chosen. This
21 selection is somewhat arbitrary but in the range of what seems clinically logical and
22 what is reported in the literature¹⁵. These distances can be easily measured using a K-
23 wire that is introduced into surgical wound until it touches bone and then can be
24 measured at the level of the screw head. It may well be, however, that a distance

1 between 2 cm and 3 cm is superior and it is very likely that the perfect distance will
2 change with the patient's size and individual anatomy. It must be mentioned that also
3 the curvature and the tilt of the rod can affect the amount of free space below it and
4 that these factors were not assessed in this study.

5 Hence, future studies may focus on the role of individual patient-related anatomical
6 factors and the configuration of the rod itself ¹⁴.

7 Until then, it remains unknown to the surgeon in the operating room how these
8 potential confounders may influence the optimal distance. Thus, this study sought to
9 find a rod-to-bone distance that is at the same time safe with regard to the greater
10 neuro-vascular bundle and can reduce harm to the smaller structures in all patients.

11

12 **Conclusion**

13 Based on this *ex vivo* anatomical model and with the limitations mentioned above in
14 mind, aiming for a rod-to-bone distance of 2 cm when applying an INFIX is the safest
15 way with regard to injury to the femoral neuro-vascular bundle and at the same time
16 leads to the least compression of more superficial structures like the LFCN, the
17 ACBFN, or the sartorius and the rectus femoris muscles. Sparing the sartorius muscle
18 when placing the supraacetabular screws and using a rod with as little lateral overlap
19 over the screw heads as possible avoids irritation of the muscle and the LFCN.

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- 3

1 **Figure legends**

2

3 **Figure 1 The INFIX**

4 (A) Anatomical relations of the INFIX. FIP: iliopsoic fascia. IL: inguinal ligament.
5 AIIS: anterior inferior iliac spine. LCFN: lateral cutaneous femoral nerve. ACBFN:
6 anterior cutaneous branches of the femoral nerve. FA: femoral artery. FV: femoral
7 vein. SC: spermatic cord. FN: femoral nerve. SM: sartorial muscle. ASIS: anterior
8 superior iliac spine. (B) Antero-posterior pelvic radiograph showing the clinical
9 application of the INFIX and demonstrating the relation of the INFIX to the osseous
10 pelvis with insertion of the screws at the level of the AIIS (d: rod-to-bone distance).
11 (C) Percutaneous application of the INFIX.

12

13 **Figure 2 Pressure measurements**

14 A balloon tamp (BT) connected to a manometric device was inserted into either the
15 *Lacuna vasorum* or the *Lacuna musculorum* underneath the inguinal ligament through
16 a suprainguinal approach and balloon pressures were measured in supine and sitting
17 position.

18 FIP: iliopsoic fascia. IL: inguinal ligament. BT: balloon tamp. FN: femoral nerve. IB:
19 iliac bone. IPM: iliopsoas muscle. EOM: external oblique abdominal muscle.

20

21

22 **Figure 3 Anatomical measurements - results**

1 The graphs show the percentages of specimens' groins where the distance of the
2 stated anatomical structure to the implant rod was less than 3 mm in supine (hip
3 extended -blue) and sitting (hip flexed - orange) position.

4

5 **Figure 4 Compression of inguinal structures with different rod-to-bone distances**

6 INFIX configurations with a rod-to-bone distance of 1 cm (A), 2 cm (B), and 3 cm
7 (C). A.,V.,N.: Femoral artery, vein, and nerve. *: LFCN. †: ACBFN.

8

9 **Figure 5 Pressure measurements - results**

10 Graph showing the changes of balloon pressure in the *Lacuna vasorum* (A) and the
11 *Lacuna musculorum* (B) when flexing the hips to 90 ° (supine to sitting position).

12

13 **Figure 6 Anatomic relations**

14 Relation of the rod to the spermatic cord (A, right groin of a male cadaver) and an
15 inguinal hernia (B, right groin of a male cadaver). (C) shows the LFCN running
16 underneath a laterally overlapping rod, being compressed by it.