Biomechanical comparison of different external fixation configurations for posttraumatic pelvic ring instability

Tiziani, Simon ; Osterhoff, Georg ; Ferguson, Stephen J ; Spreiter, Gregor ; Scheyerer, Max J ; Spinas, Gian-Leza ; Wanner, Guido A ; Simmen, Hans-Peter ; Werner, Clément M L

Abstract: Background. External fixation is useful in the primary treatment of pelvic ring injuries. The present study compared the biomechanical stability of five different configurations of an external pelvic ring fixation system. Methods. Five configurations of an anterior external pelvic ring fixation system were tested using a universal testing machine. One single connecting rod was used in group "SINGLE," two parallel connecting rods in group "DOUBLE," two and four rods, respectively, in a tent-like configuration in groups "SINGLE TENT" and "DOUBLE TENT," and a rhomboid-like configuration in group "RHOMBOID." Each specimen was subjected to a total of 2000 consecutive cyclic loadings at 1 Hz lateral compression/distraction (±50 N) and torque (±0.5 Nm) loading alternating every 200 cycles. Translational and rotational stiffness were determined at 100, 300, 500, 700, and 900 cycles. Results. The "SINGLE TENT" and "RHOMBOID" configurations already failed with a preloading of 50 N compression force. The "DOUBLE" configuration had around twice the translational stability compared with the "SINGLE" and "DOUBLE TENT" configurations. Rotational stiffness observed for the "DOUBLE" and "DOUBLE TENT" configurations was about 50% higher compared to the SINGLE configuration. Conclusion. Using two parallel connecting rods provides the highest translational and rotational stability.

DOI: https://doi.org/10.1155/2014/360165

DOI: https://doi.org/10.1155/2014/360165

Biomechanical comparison of different external fixation configurations for **posttraumatic** pelvic ring instability

Simon Tiziani[1], Georg Osterhoff, MD[1], Stephen J. Ferguson[2], Prof., Gregor Spreiter[2], Max J. Scheyerer, MD[1], Gian-Leza Spinas[1], Guido A. Wanner, Prof., MD[1], Hans-Peter Simmen, Prof., MD[1], Clément M. L. Werner, Prof., MD[1]

[1] Department of Surgery, Division of Trauma Surgery, University of Zurich, Raemistrasse 100, 8091 Zurich, Switzerland

[2] Institute for Biomechanics, ETH Zurich, HCI-E355.2 Wolfgang-Pauli-Strasse 10, 8093, Zurich, Switzerland

Corresponding author:
Simon Tiziani

Department of Surgery
Division of Trauma Surgery,
University Hospital Zurich,
Raemistrasse 100
8091 Zürich,
Switzerland
Tel: +41 44 255 1111
Fax: +41 44 255 4406

Email: simon.tiziani@uzh.ch

Abstract

Background External fixation is useful in the primary treatment of pelvic ring injuries. The present study compared the biomechanical stability of five different configurations of an external pelvic ring fixation system.

Methods Five configurations of the same anterior external pelvic ring fixation system were tested on pairs of polyoxymethylene testing cylinders using a universal testing machine with n = 3 for each sample group. One single connecting rod was used in group “SINGLE”, two parallel connecting rods in group “DOUBLE”, two and four rods, respectively, in a tent-like configuration in groups “SINGLE TENT” and “DOUBLE TENT” and four rods in a rhomboid-like configuration in group “RHOMBOID”. Each specimen was subjected to a total of 2000 consecutive cyclic loadings at 1 Hz with sinusoidal lateral compression/distraction (+/-50 N) and torque (+/- 0.5 Nm) loading alternating every 200 cycles. Translational and rotational stiffness were determined at 100, 300, 500, 700 and 900 cycles.

Results The “SINGLE TENT” and “RHOMBOID” configurations already failed with a preloading of 50 N compression force. The “DOUBLE” configuration had around twice the translational stability at 100, 300, 500, 700 and 900 cycles when compared with the SINGLE (p=.002,.003,.005,.000,and .000) and “DOUBLE TENT” (p=.001,.001,.001,.000,and .000) configurations. Rotational stiffness observed for the “DOUBLE” and “DOUBLE TENT” configurations was about 50 % higher when compared with the SINGLE configuration at 100 (p=.024/.012), 300 (p=.019/.074), 500 (p=.031/.011), 700 (p=.003/.005) and 900 cycles (p=.004/.006).

Conclusion Using two parallel connecting rods for external pelvic ring fixation provides the highest translational (lateral compression/distraction) and rotational (bending of the hip) stability.

Level of Evidence: Basic Science Study

Keywords: pelvic fracture, pelvic ring injury, external fixation, external fixator configuration

Background

Although unstable pelvic ring injuries are relatively rare(1), patients suffering from such injuries often show extensive haemorrhage(2). Blood loss can occur from osseous structures at the fracture site, venous bleeding from the sacral plexus or arterial bleeding(3). Pelvic volume increases with pelvic ring disruption, which further hinders haemostasis. The primary objective in such situations is to re-establish pelvic ring integrity and stability, reducing pelvic volume in the process(3, 4). **<u>Together with pelvic packing and clamping, external pelvic fixation has become an established adjunct for stabilizing</u>** unstable fractures and increasing chances of haemostasis(5-10). External fixation may assist haemostasis in different ways, reducing fracture surfaces, ensuring blood clot stability, stopping venous bleeding and achieving some tamponade by reducing pelvic volume(11, 12). Though it has been shown that it may not induce pressure-induced tamponade(6). There are numerous different external fixator constructs with each making different configurations possible. Furthermore there are different locations for pin anchoring in the pelvis. A supraacetabular placement of the external fixator pins has shown to be superior in stability compared to pins placed in the iliac crest(13, 14). Continuing stability of the external fixation is crucial in ensuring optimal chance for haemostasis. Patients rarely present with isolated injuries to the pelvis. Patients with concomitant abdominal injuries are frequent, making e.g. further abdominal surgery necessary(15). This and the fact that some patients are obese, has made it necessary to come up with different configurations of the external fixation construct to fit the respective situations. The following configurations, tested in this study, were in use at our University hospital when treating unstable pelvic ring fractures. The “SINGLE”

(Figure 1A) and “DOUBLE” (Figure 1B) configurations represent standard configurations. The “SINGLE TENT” (Figure 1C) and DOUBLE TENT” (Figure 1D) configurations are used where the distance from the symphysis to the skin is increased in obese patients, making the application of the “SINGLE and “DOUBLE” configurations impossible. Finally the “RHOMBOID” (Figure 1E) configuration is installed when further abdominal procedures (e.g. laparotomy) are to be expected.

The aim of the study was to compare the stability of five different configurations of the same external pelvic fixation construct. **The hypothesis was that there would be no difference in stability between the different configurations.**

Materials and Methods

Samples

The testing protocol included the testing of five different configurations of the same external fixation construct for the pelvis (Hoffmann II, Stryker, Kalamazoo, MI, USA). The groups to be tested included the following configurations: "SINGLE" (Figure 1A), "DOUBLE" (Figure 1B), "SINGLE TENT" (Figure 1C), "DOUBLE TENT" (Figure 1D) and "RHOMBOID" (Figure 1E). The fixator's pins (diameter 5mm) were inserted into polyoxymethylene cylinders (diameter 70mm) (Delrin, DuPont, Wilmington, DE, USA), one for each pin. Distance between the two polyoxymethylene cylinders and angle of pin insertion were measured at an external fixation device mounted in the supraacetabular region of a synthetic model of the pelvis (Pelvis, Synbone, Malans, Switzerland) (Figure 1F). **The pins were than screwed into the polyoxymethylene cylinders at a 45 degree angle and 7cm from the later inward facing edge, making the distance from pin entry to pin entry site 21 cm. The couplings interfacing the pins and the rods were always placed with their upper edge on the first mark on the pins. In the "TENT" and "DOUBLE-TENT" configuration the distance between the pin-rod interface and the rod-rod interface was 24 cm (in the "DOUBLE-TENT configuration this refers to the outer tent), resulting in a distance from rod-rod coupling to the surface of the cylinders of 25 cm in the plumb line. The distance from rod-pin interface to the rod-rod interface in the "RHOMBOID" configuration was 26 cm on all sides. The shapes of the different configurations were determined by an experienced orthopedic trauma surgeon (C.W).** The five different configurations were attached to the pins via the rod-pin interface couplings, which all were tightened by the same person (S.T)

Biomechanical testing

For the tests two different loading scenarios were selected. Firstly a translational loading scenario was applied, where the construct was loaded simulating compression and distraction in the pelvis. Secondly a rotational loading scenario was applied that would simulate e.g. hip bending. These two scenarios were chosen because they address the most common situations occurring in the post-op phase: patients in supine position, leg movement and patient transfer.

Thus all samples were tested using a universal testing machine (ElectroPulse E10000, Instron, Norwood, MA, USA) (Figure 2) according to the following protocol: alternating cycles of compression and distraction (along the cylindrical axis) and rotational loading (rotation around the cylindrical axis). Each sequence consisting of 200 cycles at 1 Hz was run 5 times, making a total of 2000 cycles (1000 cycles each) per sample.

After slowly loading and observing a displacement of >25mm with +/- 50N translational load, 50N was chosen for loading the cycles in translational loading. Rotational torque was set at +/- 5 Nm.

Measurements during testing were recorded by a +/-1000 N (compression/distraction forces) and a 25 Nm (torque forces) loading cell and the computer programme calculated translational and rotational stiffness. Failure, as defined in the testing protocol, leading to abort of testing included: Displacement overshooting the machine’s range of motion (+/- 30mm translation and +/- 135 degrees rotation) and/or interface or construct failure.

Evaluation:

Translational stiffness [N/mm]: Translational stiffness readings were taken at 100, 300, 500, 700 and 900 cycles to be analysed statistically. This is a measure for resisting displacement when loaded simulating lateral compression and distraction.

Rotational stiffness [Nm/degree]: Rotational stiffness readings were taken at 100, 300, 500, 700 and 900 cycles to be analysed statistically. This is a measure for resisting torque forces on the pelvis.

Statistical analysis

After preliminary testing, a sample size calculation was performed using PS Power and Sample Size Calculations 3.0 (alpha error: 0.05)(16).

With an expected difference in means of 0.5 N/mm and a standard deviation of 0.15N/mm for translational stiffness and an expected difference in means of 0.08 Nm/degree and a standard deviation of 0.025 Nm/degree for rotational stiffness the calculated number of samples to be able to reject the null hypothesis that the population means of the experimental and control groups are equal with a probability (power) of 0.8 was 3 per group.

 [Geben Sie Text ein]

Comparison of translational and rotational stiffness was done using a One-Way-ANOVA with a post-hoc Bonferroni adjustment for multiple comparisons using SPSS for Windows V20.0 (SPSS, Chicago, Illinois, USA). Differences were considered significant for values of $p < 0.05$.

Source of Funding

There was no external funding source for this investigation.

Results

The “SINGLE TENT” and the “RHOMBOID” configurations showed more than 30mm displacement before reaching 50N lateral compression-distraction loading, resulting in failure as defined by the testing protocol.

Translational stiffness (Figure 3):

The “DOUBLE” configuration was 59%-71% stiffer than the SINGLE configuration at 100, 300, 500, 700 and 900 cycles (p= .002, .003, .005, .001, and .001). Comparing it to the “DOUBLE TENT” configuration, the “DOUBLE” configuration was between 86% and 95% stiffer (p= .001, .001, .001, .001, and .001). There was no significant difference in translational stiffness between the “DOUBLE TENT” and the “SINGLE” configuration

Rotational stiffness (Figure 4):

The “DOUBLE” configuration exceeded the “SINGLE” configuration in stiffness by 35% to 60% at 100, 300, 500, 700 and 900 cycles (p= .025, .019, .031, .003, and .004). The “DOUBLE TENT” configuration was stiffer than the SINGLE configuration at 100 cycles

(41%, p= .012), 500 cycles (43%, p= .011), 700 cycles (57%, p= .005) and 900 cycles (55%, p= .006); there was no significant difference at 300 cycles. Also, there was no significant difference between the “DOUBLE” and the “DOUBLE TENT” configurations.

No permanent deformation was observed in any of the tested implants. No interface failure occurred.

Discussion

The aim of the study was to compare different configurations of the same external pelvic fixation construct, testing them for translational and rotational stiffness. **The "SINGLE" configuration showed two-third of the "DOUBLE" configuration's stiffness and the "DOUBLE" configuration was twice as stiff as the "DOUBLE TENT" configuration.** There was no significant difference between the "DOUBLE" and the "DOUBLE TENT" configurations regarding rotational stiffness. Between the "DOUBLE TENT" and "SINGLE" configuration there was a significant difference in rotational stiffness, the "DOUBLE TENT" was twice as stiff. Both the "RHOMBOID" and the "SINGLE TENT" configurations failed.

In the beginning there were efforts to devise external fixator constructs that would by themselves stabilize vertically unstable pelvic fractures. This was demonstrated not to be possible(17, 18). As soon as this was realized, complexity in external fixation construct decreased, seeing as multiple pins increase the chance for pin-track infections(19). Research has since focused on finding the optimal pin placement site(13, 20) or determining difference in stability between different fixator constructs and configurations(21-24). It was not clear how our fixation construct's stability would change when the configuration was adapted for obese patients or patients undergoing abdominal surgery.

There are a few limitations innate to the testing protocol. Failure within our test setup does not have to result in failure in the clinical setup. The testing setup was devised solely to analyse construct stiffness, ignoring additional factors like intact ligaments, soft tissue or pelvic contents that might contribute to overall stability. The upside of focusing on the construct is that we isolate the effect of different configurations on stiffness. The influence of pin anchoring strength in the bone as a possible confounding factor was avoided in this experimental setup, as all tests were conducted with the same pins anchored in the same polyoxymethylene cylinders. Rod-configuration by itself should not have an impact on pin anchoring strength. **One limitation might be that the pin-rod interfaces were not tightened by use of a torque spanner, but the same person (S.T), applying maximal force. However we are confident that this did not influence the results as no interface failure occurred and difference in stiffness was due to elastic deformation within the rods and pins rather than interface loosening.** It is possible that a bulkier configuration would be prone to screw **loosening**, being more difficult to handle in post-op care. An additional limitation is that forces on the pelvis in real patients are not limited to those addressed in this study. It is possible that the construct and its configurations react differently to a combination of translational and rotational forces or a completely different force vector.

There might be other configurations with better biomechanical properties than those tested in our study. Based on the data of the five tested, however, it seems that where the rod was in parallel alignment with the applied force (for the compression/distraction part), the stiffness was greatest. Moreover where an additional rod could be applied, a significant increase in translational stiffness was recorded. Therefore, when the circumstances (patient size, concomitant injuries,..) allow it, one should always choose a configuration where the rod is aligned parallel to the expected force vector. If possible the configuration should be augmented with an extra rod, set up the same way as the first one. The study has shown that the “DOUBLE TENT” configuration is significantly less stiff than the “DOUBLE” one. It is not possible to tell from this study whether a “TENT” configuration provides sufficient stability **in** obese patients in the clinical environment as obesity is also associated with higher loads. An alternative might be a subcutaneous internal anterior fixator, with which the distance from pin entry sites to the connecting rods can be decreased (25, 26). This method would also be an option where further abdominal surgeries are expected avoiding a potentially unstable “RHOMBOID” configuration. There is some evidence that such a device would be at least as stable as an external fixator(27).

Any future studies should look at failure of different constructs in the clinical setup and try to come up with quantifiable, maybe in-vivo, results.

Conclusion

Using two parallel connecting rods for external pelvic ring fixation provides the highest translational (lateral compression/distraction) and rotational (bending of the hip) stability.

Competing interests

None.

References

1. Balogh Z, King KL, Mackay P, et al. The epidemiology of pelvic ring fractures: a population-based study. *J Trauma*. United States; 2007:1066-1073; discussion 1072-1063.

2. Hak DJ, Smith WR, Suzuki T. Management of hemorrhage in life-threatening pelvic fracture. *J Am Acad Orthop Surg*. United States; 2009:447-457.

3. Tile M. Pelvic ring fractures: should they be fixed? *J Bone Joint Surg Br*. 1988;70:1-12.

4. Moss MC, Bircher MD. Volume changes within the true pelvis during disruption of the pelvic ring--where does the haemorrhage go? *Injury*. 1996;27 Suppl 1:S-A21-23.

5. Burgess AR, Eastridge BJ, Young JW, et al. Pelvic ring disruptions: effective classification system and treatment protocols. *J Trauma*. 1990;30:848-856.

6. Grimm MR, Vrahas MS, Thomas KA. Pressure-volume characteristics of the intact and disrupted pelvic retroperitoneum. *J Trauma*. 1998;44:454-459.

7. Riemer BL, Butterfield SL, Diamond DL, et al. Acute mortality associated with injuries to the pelvic ring: the role of early patient mobilization and external fixation. *J Trauma*. 1993;35:671-675; discussion 676-677.

8. Miller PR, Moore PS, Mansell E, et al. External fixation or arteriogram in bleeding pelvic fracture: initial therapy guided by markers of arterial hemorrhage. *J Trauma*. 2003;54:437-443.

9. Arvieux C, Thony F, Broux C, et al. Current management of severe pelvic and perineal trauma. *J Visc Surg*. 2012;149:e227-238.

10. Chen W, Hou Z, Su Y, et al. Treatment of posterior pelvic ring disruptions using a minimally invasive adjustable plate. *Injury*. 2013.

11. Bircher MD. Indications and techniques of external fixation of the injured pelvis. *Injury*. 1996;27 Suppl 2:B3-19.

12. Scaglione M, Parchi P, Digrandi G, et al. External fixation in pelvic fractures. *Musculoskelet Surg*. 2010;94:63-70.

13. Kim WY, Hearn TC, Seleem O, et al. Effect of pin location on stability of pelvic external fixation. *Clin Orthop Relat Res*. 1999:237-244.

14. Gardner MJ, Nork SE. Stabilization of unstable pelvic fractures with supraacetabular compression external fixation. *J Orthop Trauma*. United States; 2007:269-273.

15. Demetriades D, Karaiskakis M, Toutouzas K, et al. Pelvic fractures: epidemiology and predictors of associated abdominal injuries and outcomes. *J Am Coll Surg*. United States; 2002:1-10.

16. Dupont WD, Plummer WD, Jr. Power and sample size calculations for studies involving linear regression. *Control Clin Trials*. United States; 1998:589-601.

17. Wild JJ, Jr., Hanson GW, Tullos HS. Unstable fractures of the pelvis treated by external fixation. *J Bone Joint Surg Am*. 1982;64:1010-1020.

18. Pohlemann T, Krettek C, Hoffmann R, et al. [Biomechanical comparison of various emergency stabilization measures of the pelvic ring]. *Unfallchirurg*. 1994;97:503-510.

19. Tucker MC, Nork SE, Simonian PT, et al. Simple anterior pelvic external fixation. *J Trauma*. 2000;49:989-994.

20. Archdeacon MT, Arebi S, Le TT, et al. Orthogonal pin construct versus parallel uniplanar pin constructs for pelvic external fixation: a biomechanical assessment of stiffness and strength. *J Orthop Trauma*. United States; 2009:100-105.

21. Vecsei V. [Results of biomechanical studies of various external fixation devices of the pelvis]. *Aktuelle Traumatol*. 1988;18:261-264.

22. Egbers HJ, Draijer F, Havemann D, et al. [Stabilizing the pelvic ring with the external fixator. Biomechanical studies and clinical experiences]. *Orthopade*. 1992;21:363-372.

23. Rieger H, Winckler S, Wetterkamp D, et al. Clinical and biomechanical aspects of external fixation of the pelvis. *Clin Biomech (Bristol, Avon)*. 1996;11:322-327.

24. Ponsen KJ, Hoek van Dijke GA, Joosse P, et al. External fixators for pelvic fractures: comparison of the stiffness of current systems. *Acta Orthop Scand*. 2003;74:165-171.

25. Gardner MJ, Mehta S, Mirza A, et al. Anterior Pelvic Reduction and Fixation Using a Subcutaneous Internal Fixator. *J Orthop Trauma*. 2011.

26. Vaidya R, Colen R, Vigdorchik J, et al. Treatment of unstable pelvic ring injuries with an internal anterior fixator and posterior fixation: initial clinical series. *J Orthop Trauma*. 2012;26:1-8.

27. Vigdorchik JM, Esquivel AO, Jin X, et al. Biomechanical stability of a supra-acetabular pedicle screw internal fixation device (INFIX) vs external fixation and plates for vertically unstable pelvic fractures. *J Orthop Surg Res*. England; 2012:31.

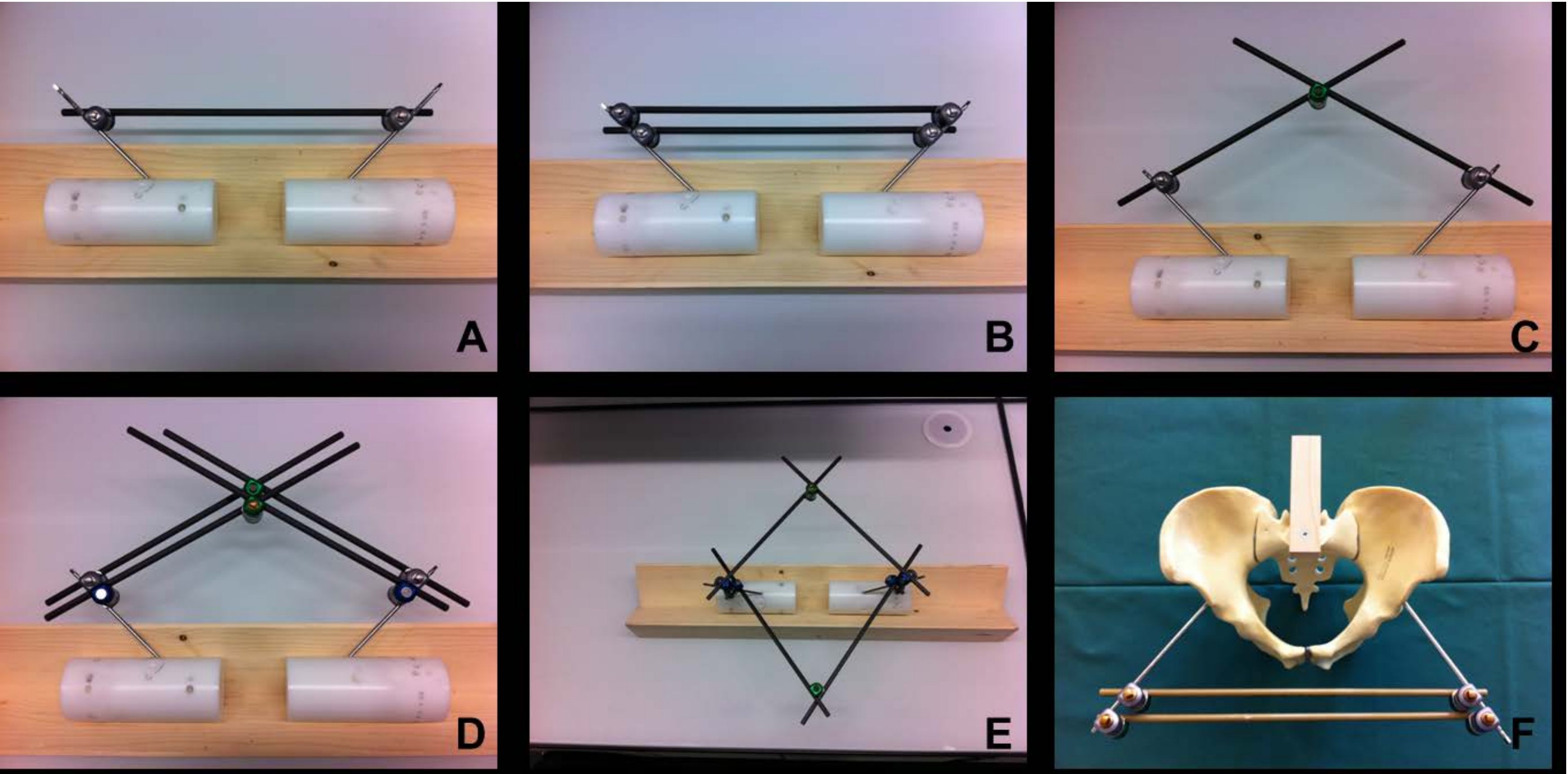
Figure legends

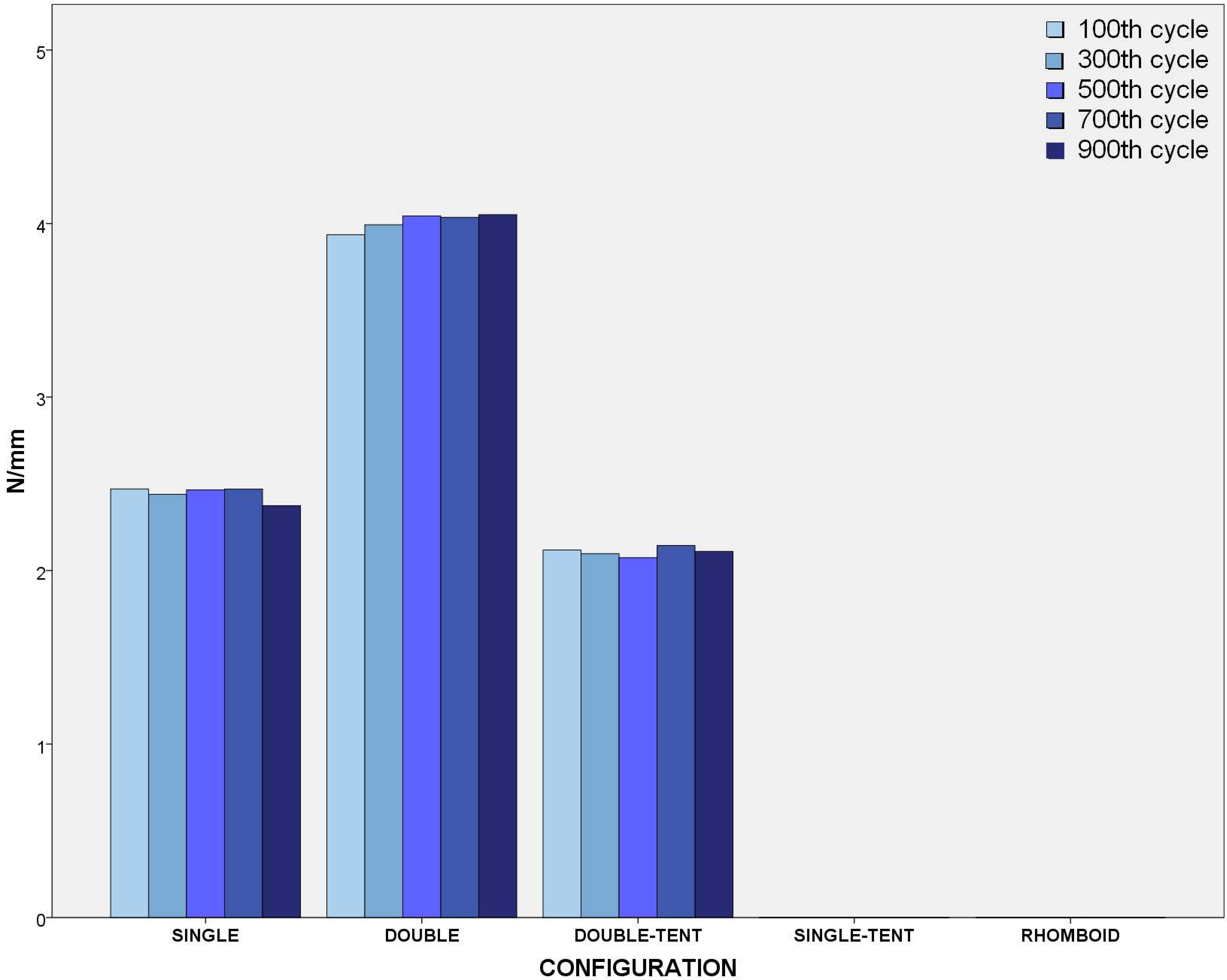
Figure 1 Configurations & pelvic instrumentation: (A) The "SINGLE" configuration. (B) The "DOUBLE" configuration. (C) The "SINGLE-TENT" configuration. (D) The "DOUBLE-TENT" configuration. (E) The "RHOMBOID" configuration. (F) A "DOUBLE" configuration mounted on a synthetic Synbone pelvis.

Figure 2 Experimental setup: Two polyoxymethylene cylinders instrumented with a Hoffmann II external fixator in the "DOUBLE-TENT" configuration mounted on the Intron testing machine. Testing included compression/distraction and rotational loading.

Figure 3 Translational stiffness: Results for translational stiffness of the five different configurations at 100, 300, 500, 700, 900 cycles. The "SINGLE-TENT" and the "RHOMBOID" configuration failed and thus yielded no results.

Figure 4 Rotational stiffness: Results for rotational stiffness of the five different configurations at 100, 300, 500, 700, 900 cycles. The "SINGLE-TENT" and the "RHOMBOID" configuration failed and thus yielded no results.


A
B
C
D
E
F


100th cycle
300th cycle
500th cycle
700th cycle
900th cycle
N/mm
5
4
3
2
1
0
SINGLE
DOUBLE
DOUBLE-TENT
SINGLE-TENT
RHOMBOID
CONFIGURATION

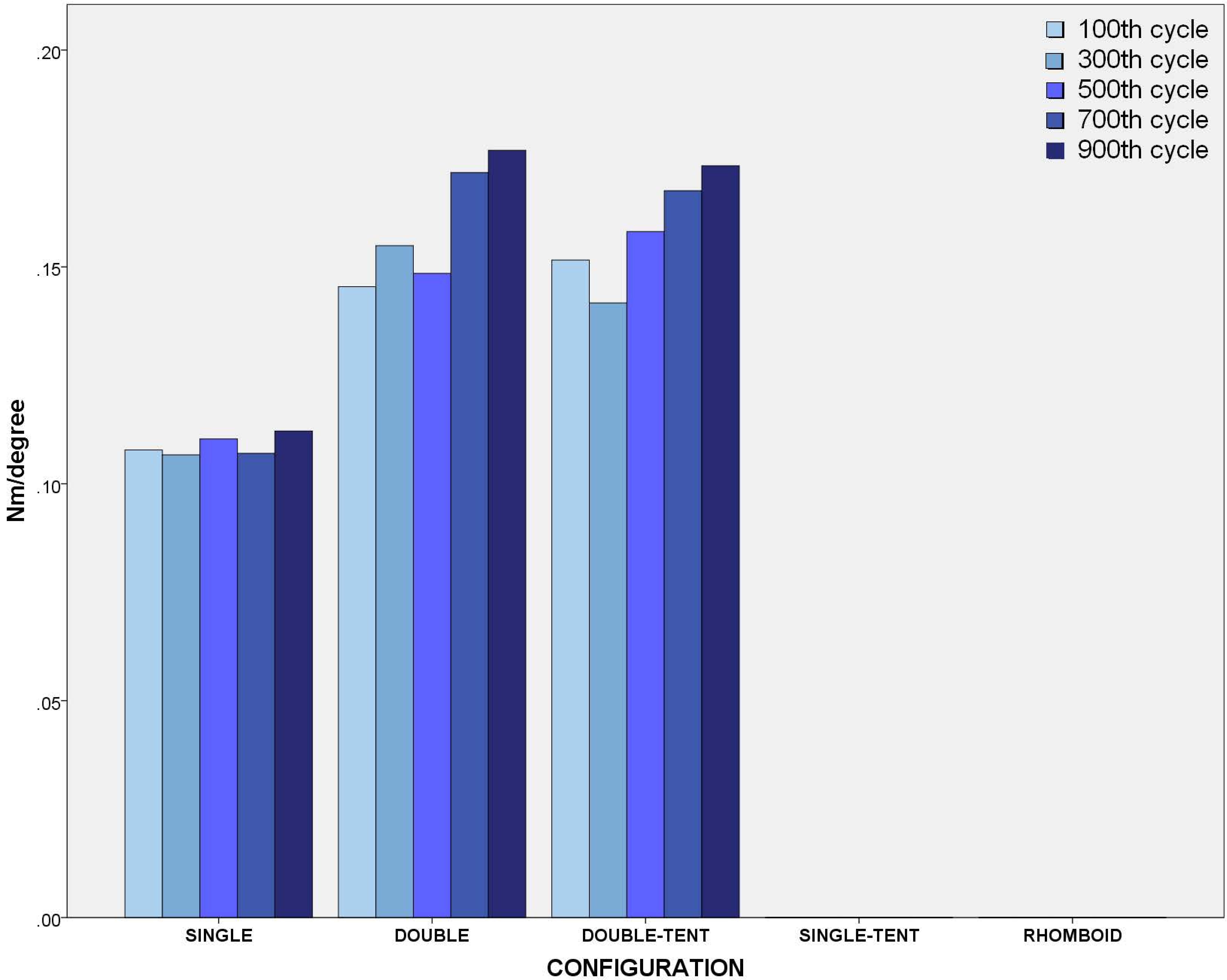

100th cycle
300th cycle
500th cycle
700th cycle
900th cycle
.20
.15
.10
.05
.00
Nm/degree
SINGLE
DOUBLE
DOUBLE-TENT
SINGLE-TENT
RHOMBOID
CONFIGURATION

Figure legends

Figure 1 Configurations & pelvic instrumentation: (A) The “SINGLE” configuration. (B) The “DOUBLE” configuration. (C) The “SINGLE-TENT” configuration. (D) The “DOUBLE-TENT” configuration. (E) The “RHOMBOID” configuration. (F) A “DOUBLE” configuration mounted on a synthetic Synbone pelvis.

Figure 2 Experimental setup: Two polyoxymethylene cylinders instrumented with a Hoffmann II external fixator in the “DOUBLE-TENT” configuration mounted on the Intron testing machine. Testing included compression/distraction and rotational loading.

Figure 3 Translational stiffness: Results for translational stiffness of the five different configurations at 100, 300, 500, 700, 900 cycles. The “SINGLE-TENT” and the “RHOMBOID” configuration failed and thus yielded no results.

Figure 4 Rotational stiffness: Results for rotational stiffness of the five different configurations at 100, 300, 500, 700, 900 cycles. The “SINGLE-TENT” and the “RHOMBOID” configuration failed and thus yielded no results.