33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

Effect of Force Tightening on Cable Tension and Displacement in Greater Trochanter Reattachment

Fanny Canet, Kajsa Duke, Yan Bourgeois, G-Yves Laflamme, Vladimir Brailovski, Yvan Petit

Abstract: **The purpose of this study was to evaluate cable tension during installation, and during loading similar to walking in a cable grip type greater trochanter (GT), reattachment system.**
A 4th generation Sawbones composite femur with osteotomised GT was reattached with four Cable-Ready® systems (Zimmer, Warsaw, IN). Cables were tightened at 3 different target installation forces (178, 356 and 534 N) and retightened once as recommended by the manufacturer. Cables tension was continuously monitored using in-situ load cells. To simulate walking, a custom frame was used to apply quasi static load on the head of a femoral stem implant (2340 N) and abductor pull (667 N) on the GT. GT displacement (gap and sliding) relative to the femur was measured using a 3D camera system.
During installation, a drop in cable tension was observed when tightening subsequent cables: an average 40±12.2% and 11±5.9% tension loss was measured in the first and second cable. Therefore, retightening the cables, as recommended by the manufacturer, is important.
During simulated walking, the second cable additionally lost up to 12.2±3.6% of tension. No difference was observed between the GT-femur gaps measured with cables tightened at different installation forces (p=0.32). The GT sliding however was significantly greater (0.9±0.3 mm) when target installation force was set to only 178 N compared to 356 N (0.2±0.1 mm); p<0.001. There were no significant changes when initial tightening force was increased to 534 N (0.3±0.1 mm); p=0.11.
In conclusion, the cable tightening force should be as close as possible to that recommended by the manufacturer, because reducing it compromises the stability of the GT fragment, whereas increasing it does not improve this stability, but could lead to cable breakage.

Manuscript received April 14, 2011. This study was funded in part by the Canadian Foundation for Innovation (CFI) and the Natural Science and Engineering Research Council of Canada (NSERC).

F. C. Author is with Hôpital du Sacré-Coeur, Montréal, Canada (corresponding author. Phone: 514 338 2222 *3712 Fax: 514 338 2694. E-mail : fanny.canet@crhsc.rtss.qc.ca)
K. D. Author was with the mechanical engineering department, École de Technologie Supérieure, Montreal, Canada and is now with mechanical engineering department, University of Alberta, Edmonton, Alberta, Canada (e-mail: kajsa.duke@ualberta.ca)
Y. B. Author was with the mechanical engineering department, École de Technologie Supérieure, Montreal, Canada (e-mail: yan_bourgeois@hotmail.com)
G-Y. L. Author is with Hôpital du Sacré-Coeur, Montréal, Canada (e-mail yveslaflamme@gmail.com)
V. B. Author is with the mechanical engineering department, École de Technologie Supérieure, Montreal, Canada (e-mail: vladimir.brailovski@etsmtl.ca)
Y. P. Author is with the mechanical engineering department, École de Technologie Supérieure, Montreal, Canada and Research center, Hôpital du Sacré-Coeur, Montréal, Canada (e-mail: yvan.petit@etsmtl.ca)

INTRODUCTION

During hip revision surgery, an osteotomy of the greater trochanter (GT) is often performed to improve exposure. Moreover, fracture of the greater trochanter is a possible complication (3 to 7%) of hip replacement surgery [1]. Therefore, it becomes necessary to reattach GT to the femur. Biomechanical analysis of GT reattachement began in the late 1970's when only wires were used [2]. More recently, cables and cable plate systems have been introduced. Hersh *et al.* [3] compared the stiffness of wire, cable and a short Dall Miles Two Cable Grip system (Howmedica, Rutherford, NJ). The cable grip system was found to be the strongest and the most rigid of the three [3]. Regardless, a relatively high failure rate is still reported [4] and complications such as cable loosening, cable breakage, non-union, bursitis are reported [5, 6]. Barrack *et al.* [4] compared two generations of cerclage cables. They reported a relatively high rate of non-union (15 to 36%) and cable breakage (19 to 41%) with both systems. Similar results were underlined by Ritter *et al.* [7] in 40 hips with 33% of cable breakage and 38% of non-union. Koyama *et al.* [8] observed 29% of cables breakage and 31% non-union in a study on 62 revision THA.

The purpose of this work is to study the impact of the "Cable-Grip" installation forces on the cable tension variations and GT displacements during loading similar to walking.

I. METHODS

A 4th generation Sawbones composite femur (Pacific Research Laboratories Inc. Vashon, WA) was osteotomised to simulate a GT fracture using a custom-made jig to ensure reproducible cut. The use of a synthetic femur model was preferred in this study for the reliability of its mechanical behaviour [9, 10]. The composite femur was implanted with a femoral stem by an orthopaedic surgeon.

The GT was then reattached with a Cable-Ready® reattachment system (Zimmer, Warsaw, IN) using 1.8 mm diameter Cobalt-Chrome cables (Figure 1).

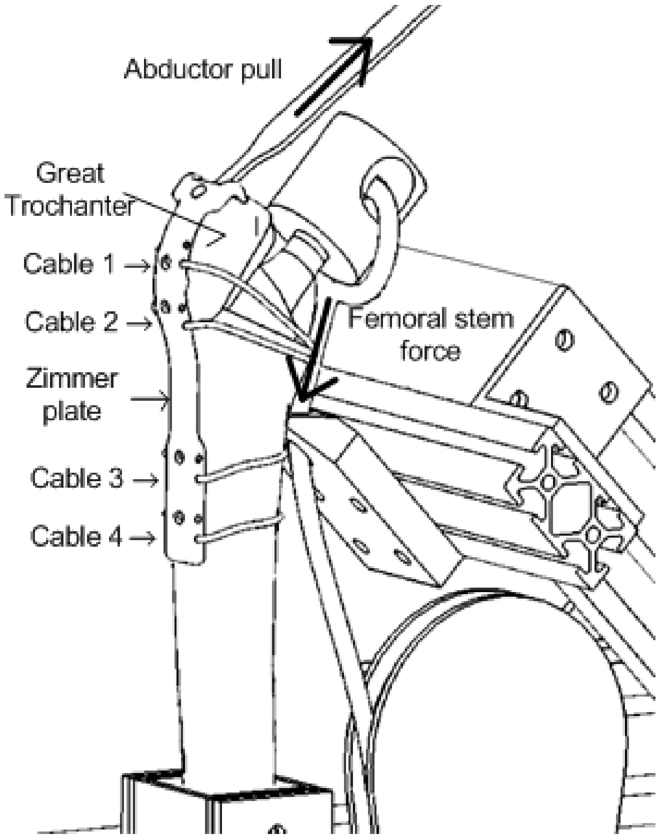

Figure 1: Experimental set-up to simulate walking loads on a femur model with GT reattachment

The cables were tightened from the proximal to distal. The tension was monitored with a through-hole compression load cell (Omegadyne, Sunbury, OH, USA) in all cables. The cables were then retightened to the target tension as advised by the manufacturer. The target cable tension was set to 50, 100 and 150% of the manufacturer's recommended load (356 N ie 80 lbs).

A custom made frame (Figure 1) was used to apply quasi static load of 2340 N on the head of the femoral stem implant and 667 N abductor pull on the GT to simulate walking [11]. The loads on femoral implant and the GT were applied in accordance with the magnitude and direction reported by Heller *et al* [12]. This loading was applied three times to evaluate the effect of walking. The cycling was repeated 3 times for a total of 9 trials for each tightening tension.

The Femur and GT displacement was measured with an Optotrak 3D camera system (Northern Digital inc., Canada). The x, y and z coordinates of 2 rigid bodies associated with the GT and the femur were recorded. Then GT displacements with respect to the femur were evaluated using two measures: the maximum gap (displacement perpendicular to the osteotomy plane) and the maximum sliding (displacement in the osteotomy plane). The gap and sliding were measured at the 3 peaks loads. Comparison of the gap and sliding were done at the last peak using ANOVA and Student's t-test.

II. RESULTS

A. *Cable tension when tightening*

It was observed that each cable lost tension when subsequent cables were tightened. The tension loss in each cable is summarized in percentage of the installation force (Table 1).

TABLE I
LOSS IN CABLE TENSION WHEN TIGHTENING THE SUBSEQUENT CABLES (IN PERCENT OF THE INSTALLATION FORCE)

Installation Force, N	Loss in tension, %		
	Cable 1	Cable 2	Cable 3
178	39.4±1.5	18.2±3.9	1.7±0.8
356	51.5±14.8	8.3±2.3	0.8±0.2
534	29.6±3.5	7.7±3.4	0.9±0.5
All tensions	40.2±12.2	11.4 ±5.9	1.2±0.7

The first cable (proximal) lost in average 40% of its initial tension when the second cable was tightened. The second cable lost in average 11% when the third cable was tightened. No significant loss was observed in the third cable when the fourth was tightened. When tightening the third cable, there was no change in the first cable (less than 3 percent in the 3 cases). When tightening the fourth cable, the tension in the first cable increased by 15% (compared to the installation force) when tightening at 178 N, 25% when tightening at 356 N.

Since during installation of all four cables, tension of the first two cables significantly fluctuated, retightening was needed to reset each cable at the target installation force (see Figure 2).

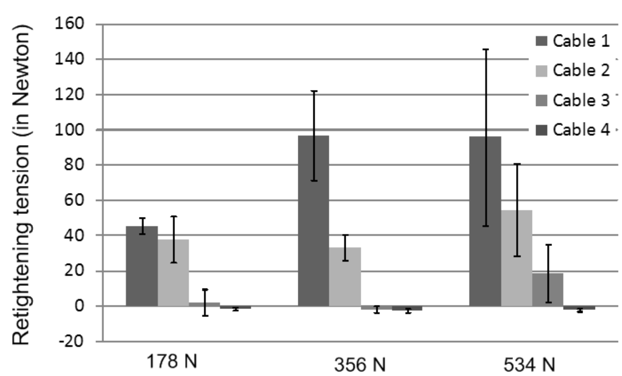

Figure 2: Retightening force after the first tightening of the four cables.

Decreasing the target installation force compared to the recommended force (178 instead of 356 N) reduced the absolute loss in tension in the first cable that should be compensated by retightening (45±4 vs 97±25 N), but had no effect on the second cable (38±13 vs 33±7 N). Increasing the target installation force (534 instead of 356 N) had no effect on the first cable (96±50 vs 97±25 N), but increased the loss in tension in the second cable (33±7 vs 55±26 N). After 178 and 356 N initial tightening forces, the third and fourth cables did not required any retightening, whereas after initial tightening at 534 N, the third cable required a slight retighetening (19±16 N).

B. Cable tension during walking simulation

The cable tension was continuously monitored during three steps of walking to analyze potential cable loosening. Table II summarizes all the tension losses in percent of the installation force while applying walking load.

TABLE II
LOSS OF TENSION AFTER THREE CYCLING OF WALKING
(IN PERCENT OF THE INSTALLATION FORCE)

Installation Force, N	Loss in tension, %			
	Cable 1	Cable 2	Cable 3	Cable 4
178	-3.2±3.8	7.8±2.0	5.6±6.1	-1.3±3.2
356	4.4±0.3	13.4±1.4	1.3±0.9	1.7± 1.0
534	8.3± 0.1	15.2± 1.3	2.4± 1.8	2.6±1.4
All tensions	3.2±. 3.6	12.2±3.6	3.1±. 3.8	1.0± 2.5

All cables loosen after testing with the exception of the first and fourth cable when tensioned to 178 N. The second cable observed the greatest loss in each case: 8, 13 and 15% was lost when tightening at 178, 356 and 534 N, respectively. Increasing the target installation force did not have any positive impact in terms of avoiding cable loosening during walking.

With the manufacturer's recommended initial tension (356 N), the cables lost in average 4, 13, 1 and 2% for the first, the second, the third and the last cable, respectively. As shown in Figure 3, most of the loosening occurred in the second cable during the first loading step. Figure 3 also shows a continuous decrease in tension along the loading steps.

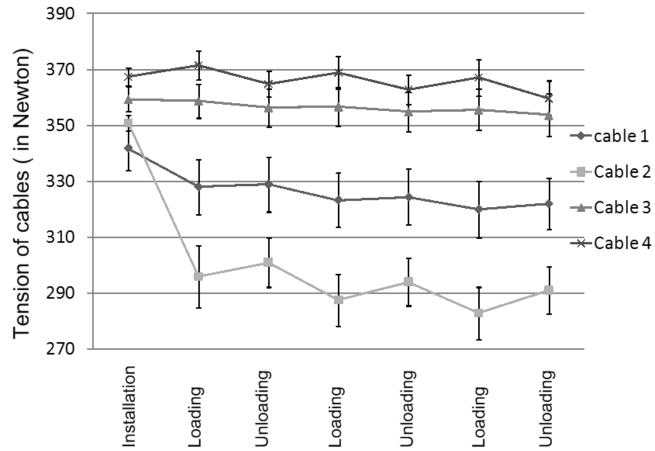

Figure 3: Loss of tension during 3 steps of walking when applying the manufacturer's recommended tension (356 N)

C. GT Gap during walking simulation

As shown in Figure 4, gap displacement remains globally constant (0.39, 0.46 and 0.42 mm) for all the target installation forces. No difference was found between the gap displacements for different target installation forces (p=0.32). However, the gap was more variable at the smallest installation force.

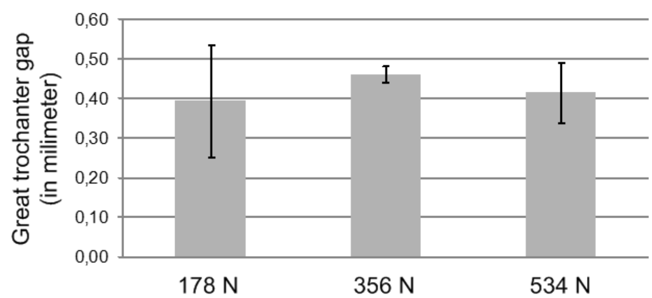

Figure 4: GT gap displacement after 3 steps of walking load

D. GT sliding during walking simulation

As shown on Figure 5, decreasing the tightening tension significantly increased the GT sliding displacement ($p<0.001$): at 178 N, the GT displacement was of 0.89 mm compared to 0.24 mm when tightening at the recommended manufacturer installation force (356 N). Increasing the installation force had no effect ($p=0.11$) on the GT sliding displacement (0.24 vs 0.26 mm).

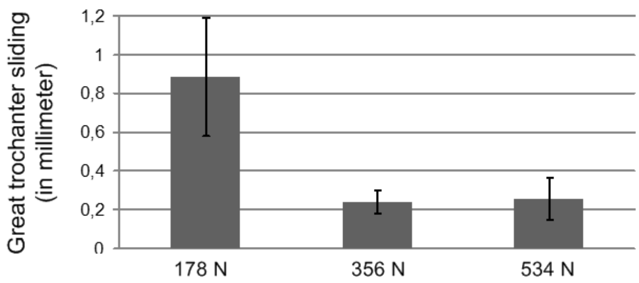

Figure 5: GT sliding displacement after 3 steps of walking load

III. DISCUSSION

During installation, an important loss in cable tension was observed when tightening subsequent cables. These results confirm that it is important to properly retighten the cables as suggested by the manufacturer.

During walking, a loss in cable tension was measured after the simulation of only three walking steps, and the most important loss occurred in the second cable (12%). Effect of the long term cycling was not tested in this study.

During walking simulation, GT sliding displacements between 0.2 and 0.9 mm were observed. Even such small displacements may be significant and lead to fibrous union rather than bony union. With a fracture or osteotomy gap of less than 1 mm, rigid fixation and absolute stability is needed to reduce gap strain under 10 %.

More variability in GT displacement was observed when the cables were tightened at only 50% of the manufacturer recommended tension, suggesting that a reduction in installation force may lead to instability. Moreover, since no difference was observed between the sliding and gap displacements when the cables were tensioned at 356 or 534 N, excessive tightening of the cables is also not recommended, as it provides no advantage in displacement and it may increase local stress concentration at the bone-cable interface and lead to either cable or bone failure.

IV. CONCLUSION

This study is the first to analyze the cable tension during installation and simulating walk. This innovative methodology will be used for several other studies monitoring the loss of tension in cables during installation depending on the set-up configuration, number and type of cables, plates design, etc.

ACKNOWLEDGMENTS

Authors would like to thank Charles Toueg, Yannick Baril and Michel Drouin for their technical help.

REFERENCES

[1] A. M. Claus, *et al.*, "Fractures of the greater trochanter induced by osteolysis with the anatomic medullary locking prosthesis," *J Arthroplasty,* vol. 17, pp. 706-12, Sep 2002.

[2] K. L. Markolf, *et al.*, "Mechanical stability of the greater trochanter following osteotomy and reattachment by wiring," *Clin Orthop Relat Res,* pp. 111-21, Jun 1979.

[3] C. K. Hersh, *et al.*, "Comparison of the mechanical performance of trochanteric fixation devices," *Clin Orthop Relat Res,* pp. 317-25, Aug 1996.

[4] R. L. Barrack and R. A. Butler, "Current status of trochanteric reattachment in complex total hip arthroplasty," *Clin Orthop Relat Res,* vol. 441, pp. 237-42, Dec 2005.

[5] R. P. Clarke, Jr., *et al.*, "Trochanteric osteotomy: analysis of pattern of wire fixation failure and complications," *Clin Orthop Relat Res.,* pp. 102-110., 1979.

[6] H. C. Amstutz and S. Maki, "Complications of trochanteric osteotomy in total hip replacement," *J Bone Joint Surg Am.,* vol. 60, pp. 214-6., 1978.

[7] M. A. Ritter, *et al.*, "Trochanteric fixation by cable grip in hip replacement," *J Bone Joint Surg Br,* vol. 73, pp. 580-1, Jul 1991.

[8] K. Koyama, *et al.*, "Reattachment of the greater trochanter using the Dall-Miles cable grip system in revision hip arthroplasty," *J Orthop Sci,* vol. 6, pp. 22-7, 2001.

[9] A. M. Ali, *et al.*, "Experimental model of tibial plateau fracture for biomechanical testing," *J Biomech,* vol. 39, pp. 1355-60, 2006.

[10] A. S. Landsman and T. J. Chang, "Can synthetic bone models approximate the mechanical properties of cadaveric first metatarsal bone?," *J Foot Ankle Surg.,* vol. 37, pp. 122-7; discussion 172., 1998.

[11] Y. Baril, *et al.*, "Testing system for the comparative evaluation of greater reattachment devices," *Exp Techs,* 2011.

[12] M. O. Heller, *et al.*, "Determination of muscle loading at the hip joint for use in pre-clinical testing," *J Biomech,* vol. 38, pp. 1155-63, May 2005.