

# A small number of stair climbing cycles during daily patient functioning, substantially increases the risk of mechanical failure of cemented THA implants

***Citation for published version (APA):***

Stolk, J., Verdonschot, N. J. J., & Huiskes, H. W. J. (2002). A small number of stair climbing cycles during daily patient functioning, substantially increases the risk of mechanical failure of cemented THA implants. In *48th Annual meeting of the Orthopaedic Research Society* Article Poster 1001 Orthopaedic Research Society.

***Document status and date:***

Published: 01/01/2002

***Document Version:***

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

***Please check the document version of this publication:***

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

[Link to publication](#)

***General rights***

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

[www.tue.nl/taverne](http://www.tue.nl/taverne)

***Take down policy***

If you believe that this document breaches copyright please contact us at:

[openaccess@tue.nl](mailto:openaccess@tue.nl)

providing details and we will investigate your claim.

# A SMALL NUMBER OF STAIR CLIMBING CYCLES DURING DAILY PATIENT FUNCTIONING, SUBSTANTIALLY INCREASES THE RISK OF MECHANICAL FAILURE OF CEMENTED THA IMPLANTS

\*Stolk, J (A-European Union); +\*Verdonschot, N; \*\*Huiskes, R

+\*Orthopaedic Research Lab, Nijmegen, The Netherlands. +31 24 3617080, Fax: +31 24 3540555, n.verdonschot@orthp.azn.nl

**Introduction:** Retrieval studies have shown that stem-cement debonding and subsequent cement cracking are common events around the femoral component of cemented total hip arthroplasty (THA) reconstructions [1]. According to the damage accumulation failure scenario [2], these events promote aseptic loosening of the implant. The damage accumulation rate in the cement mantle is related to mechanical loading of the implant *in vivo*. In this respect, it has been suggested that stair climbing is more detrimental to the reconstruction than level walking, due to increased torsional loading [3]. However, it is yet unknown how stair climbing affects the damage accumulation process on the long term. Furthermore, the frequency of stair climbing cycles in the activity pattern is generally low. Active patients perform approximately one stair climbing cycle for every 9 walking cycles [4]. It remains questionable whether the damage accumulation rate is really much higher in these patients who climb many stairs, compared to patients who climb no stairs at all. To confirm the general believe that stair climbing is a riskfull activity, we investigated how a loading history of isolated stair climbing affected the damage accumulation in the cement, compared to a loading history of isolated walking. Furthermore, we investigated how much higher the damage accumulation rate is in patients who climb many stairs, compared to patients who climb no stairs at all.

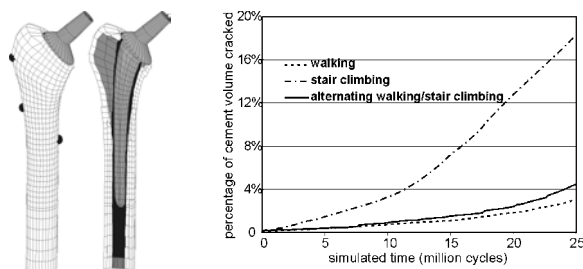


Fig. 1: FE model and Fig. 2: Cracked cement volume as a percentage of total cement volume versus simulated time.

**Methods:** A 3-D FE model was created (Fig. 1), representing a cemented hip joint reconstruction with a Lubinus SPII stem (Waldemar Link GmbH, Hamburg, Germany) in a left composite femur (Pacific Research Labs, WA, USA). The geometry of the cement mantle and the position of the stem were determined from real composite reconstructions, as created by an experienced surgeon. The material properties of the cement were taken from [5]. All other properties were taken from standard materials handbooks. The stem-cement interface was modeled as debonded ( $\mu=0.25$ ).

Loading conditions around the hip joint during the most strenuous phases of the stair-climbing and walking cycle, were taken from [7] and [8]. The configurations included the hip joint contact force, the glutei, the tensor fasciae latae, the iliotibial tract and the vastus lateralis and medialis (Fig. 1). Particularly the hip joint force and the abductor force were directed more antero-posteriorly during stair-climbing than during gait, subjecting the reconstruction to a higher torsional load. Damage accumulation in the cement mantle was simulated for three different loading histories. In the first one, the stair-climbing loads were applied repeatedly to the FE model, to represent 25 million cycles of isolated stair climbing. In the second history, the gait loads were applied repeatedly, to represent 25 million cycles of isolated walking. This history was assumed to be representative for patients who climb no stairs at all. In the third history, the stair-climbing loads and the gait loads were applied alternatingly, in blocks of 250.000 stair-climbing cycles and 2.250.000 gait cycles, until a total of 25 million load cycles was reached. The latter history was assumed to be representative for active patients who climb many stairs.

To simulate the damage accumulation process in the cement mantle, a 3-D continuum damage mechanics approach was used. In such an approach, micro-damage is thought to occur at each location in the cement mantle, as a function of the number of loading cycles and the stress levels to which the cement is locally subjected. As the simulation progresses cracks are formed in the cement, reducing the load carrying capabilities of the cement and causing the stem to migrate within the mantle.

**Results:** Stair climbing appeared to be much more detrimental to the cement mantle than walking (Fig. 2). After 25 million cycles of isolated stair climbing, approximately 17.6 % of the total cement volume contained a crack. In contrast, after 25 million cycles of isolated walking, only 2.9 % of the total cement volume contained a crack. After 25 million cycles of alternating loading, 4.3 % of the cement volume had cracked.

During isolated stair climbing, damage regions were formed medially and laterally along the full length of the stem (Fig. 3). During isolated walking, the damaged regions remained concentrated laterally around the tip and proximally-medially below the collar. During the alternating loading history, damage was additionally found on the medial side at the mid-stem level.

During all three loading histories, the head center of the stem migrated mostly posteriorly, somewhat less medially and only slightly distally (Fig. 4). This indicates that the migration pattern of the stem was governed by rotation of the stem around its long axis due to torsional loading. After 25 million cycles of isolated stair climbing the medial and posterior components of the migration were a factor of 2.75 higher than those after 25 million cycles of isolated walking. At the end of the alternating loading history, the medial and posterior components were 1.15 to 1.2 times higher than those after 25 million cycles of isolated walking.

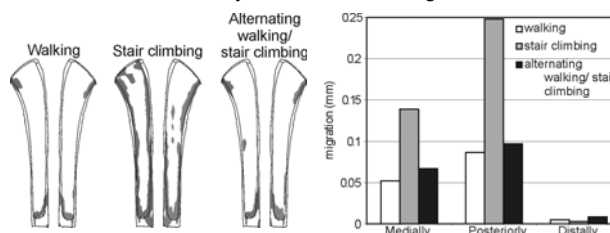


Fig. 3: Damaged regions (gray) in the cement after 25 million loading cycles (mantle is split open). Fig. 4: Migration of head center of the cement after 25 million loading cycles.

**Discussion:** During isolated stair-climbing the cement damage and the stem migration were increased drastically, compared to a history of isolated walking. In addition, isolated stair climbing produced a different failure mechanism of the cement mantle. During stair climbing the entire cement mantle was involved in the failure process, whereas during walking the cement damage remained concentrated around the tip and below the collar. Interestingly, the hip and abductor force magnitudes were rather similar for walking and stair climbing. The main difference was the increased torsional component during stair climbing. Hence, torsion plays an important role in the failure process of cemented reconstructions.

The alternating loading history was representative for active patients climbing many stairs. Relative to the case of isolated walking, an inclusion of only 10% stair climbing cycles in the loading history, increased the cement damage with approximately 47% and the stem migration with 15 to 20%. Hence, the effect of stair climbing is not proportional with the number of stair climbing cycles performed.

In conclusion, the detrimental effect of stair climbing, relative to walking, is confirmed in the present study. Stair climbing is more risky for failure of cemented THR stems than normal walking. A relatively small number of stair climbing cycles already has a considerable effect on the damage accumulation rate and, thus, on the lifetime of the reconstruction.

**Acknowledgements:** EU project SMT4-CT96-2076. Dr. Duda, Dr. Bergmann and Dr. Morlock are thanked for supplying patient activity data.

**References:** [1] Jasty et al., J Bone Joint Surg Br 73: 551-558, 1991; [2] Huiskes, Acta Orthop Scan 64: 699-716, 1993; [3] Harrigan et al., J Biomech 24: 1047-1058, 1991; [4] Morlock et al., J Biomech 34: 873-882, 2001; [5] Murphy et al., J Mater Sci 10: 779-781, 1999; [6] Stolk et al., Trans 46th Ann Meet ORS, Orlando, FL, USA; [7] Bergmann et al., J Biomech 34: 859-872, 2001; [8] Heller et al, J Biomech 34: 883-894, 2001.

\*\*Eindhoven University of Technology, Eindhoven, The Netherlands.