

Biomechanics of noncemented total hip arthroplasty

Citation for published version (APA):

Huiskes, H. W. J. (1992). Biomechanics of noncemented total hip arthroplasty. *Journal of the Japanese Orthopaedic Association*, 66(8), 1275-1276.

Document status and date:

Published: 01/01/1992

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.
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- The final published version features the final layout of the paper including the volume, issue and page numbers.

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BIOMECHANICS OF NONCEMENTED TOTAL HIP ARTHROPLASTY

R. Huiskes, Ph.D.*

Introduction: Noncemented Total Hip Arthroplasty (THA) has been developed particularly for the young, active patients. It was hoped that the frequent aseptic failures of cemented prostheses in this age group could be avoided with noncemented designs and that revisions would be less tedious. Several designs have been developed in the last 15 years, which can be categorized according to their fixation method as hydroxyl-apatite coated, porous-ingrowth coated, non-coated-press-fitted or screwed. Although little clinical information is available about recent types, many of the earlier designs have not lived up to their expectations, in particular on the femoral side. Problems encountered were thigh pain, probably caused by inadequate fit and initial stability, interface osteolysis and loosening, and stress shielding, causing bone resorption. The biomechanical aspects of these problems will be reviewed in this lecture.

Prosthetic fit: Fit depends on two factors. First of all, the relationship between the shape of the implant in relation to the bone space available within the cortical envelope, and secondly the efficacy of the surgical instruments for the creation of a precise cavity. The first factor has created severe problems, because of the natural inter-patient variations in bone shapes. Particularly the lack of dimensional correlations between the femoral metaphysis and diaphysis has created problems, which were not easily solved even with extensive size-series of implants. The surgical reaming technique is rather crude, from a technological point of view,

and will seldom result in reasonable precision of the cavity relative to the prosthesis. As a result, the prosthetic components usually do not fit well, and the relationship between proximal and distal fit is unpredictable. There is no trivial solution to this problem.

Initial stability and interface integrity: Inadequate fit causes inadequate initial stability, which leads to interface micro-motions, thigh pain, lack of bony ingrowth and interface osteolysis. Several measurement techniques have been developed in the recent past, such as Roentgen-Stereophotogrammetric Analysis (RSA), suitable to test prosthetic components relative to these aspects, pre-clinically and clinically. It will also be shown that conceptual designs can be tested in the pre-manufacturing stage using advanced Finite Element Analysis (FEA).

Stress shielding and bone resorption: Particularly around noncemented, stiff canal filling and bonded femoral stems, the bone stresses are reduced relative to normal ('stress shielding'). In accordance with 'Wolff's Law' the effect of this is bone resorption, which may extent to the order of 50 percent proximal bone loss on the mid-long term. Based on the original hypothesis of Wolff, computer simulation programs have been developed to predict the long-term loss of bone. These programs are based on a combination of FEA and strain-adaptive bone-remodeling theories. Using this method, it will be shown how the bone-resorption process depends on prosthetic-design parameters (stem shape, stem material, coating placement, bonding characteristics), on surgical technique (fit characteristics), and on patient factors (bone reactivity, patient weight and activity level).

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II-1-S₃-1

表面窒化法によるタチン合金の骨結合性の向上

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Key words: Nitrided titanium alloy, Cell compatibility, Vickers hardness
Wear debris toxicity

【目的】Ti-6Al-4V合金は生体適合性が高く、人工骨・関節などに広く利用されているが、骨結合性については不満な点も多い。我々はチタンおよびチタン合金の表面をガス窒化することにより骨結合性の高い傾斜機能材料を開発した。

【方法】焼結Ti、鍛造Ti、焼結Ti-6Al-4V、鍛造Ti-6Al-4VをN₂ガス気流中で850℃、16時間加熱して表面を窒化した。窒化処理後の窒化層は研磨しながらVickers硬度を測定し、Vickers硬度の深さ方向への変化を調べた。溶解性の評価には中性溶解液として生理的食塩水、酸性溶解液として5%リン酸、pH5塩酸、5%塩酸を用いた。

37℃擬似体液中でアルミナ、Y部分安定化ジルコニア(PSZ)、水酸アパタイト(HAP)、窒化鍛造Ti-6Al-4Vディスク(40mmφ×6mm)対UHMWPE(9mmφ×13mm)の、往復動によるPin-on-Flat摩耗試験を、静荷重223N、ストローク25mm、速度1Hzの条件で25万回行った。試験前及び試験後の擬似体液をオートクレーブで120℃、30分滅菌後、10%牛胎児血清を含むEagleMEM倍地に20%添加してコントロール培地及び試験培地を調製した。マウス線維芽組織由来L929細胞を、これらの培地で培養して増殖曲線を求めた。摩耗試験後の擬似体液はポアサイズ0.22μmのミリポアフィルターで濾別し、濾液は化学分析と細胞毒性試験を行った。

【結果】Vickers硬度は窒化鍛造Ti最表層で1170、窒化鍛造Ti-6Al-4V最表層で930であり、表面から内部に向かって徐々に小さくなり、深さ50~60μmでそれぞれ一定値120、210に収束した。ピッカース硬度120、210はそれぞれ母材のピッカース硬度に相当するため、窒化層の厚さは50~60μmであることがわかった。

試料を各溶解液中で5日間浸漬後の溶出金属量については、生理的食塩水中及びpH5塩酸中では各材料とも溶出イオンは0.1mg/l以下であり、耐食性に差は認められなかった。5%リン酸中では各材料とも焼結金属より鍛造金属の方が耐食性が高く、鍛造することで溶出量は焼結金属の60~70%に減少した。表面窒化の効果は鍛造の効果よ

りも高く、窒化により溶出量は非窒化の場合の10~16%に減少した。最も条件の厳しい5%塩酸中では表面窒化の効果はさらに顕著であり、耐食性に劣る焼結Ti-6Al-4Vでも窒化により溶出量が非窒化の場合の0.4%に減少し、鍛造Tiとはほぼ同等の耐食性を示した。各試料の表面性状は生理的食塩水、pH5塩酸、5%リン酸浸漬では変化が認められなかったが、5%塩酸浸漬では焼結Ti、鍛造Ti-6Al-4V、焼結Ti-6Al-4Vの表面が一部エッチングされ、多孔状を呈していた。窒化した試料及び鍛造Tiは5%塩酸浸漬後においても、表面性状に変化は認められなかった。図にL929細胞の増殖曲線を示す。UHMWPEのアルミナ及び窒化鍛造Ti-6Al-4Vに対する摩耗量は200万回までの累積でそれぞれ0.036mg、0.038mgである。UHMWPEのアルミナ及び窒化鍛造Ti-6Al-4Vに対する摩耗量200万回までの累積でそれぞれ0.038mgである。UHMWPE-アルミナ摩耗試験後の擬似体液はUHMWPE-窒化鍛造Ti-6Al-4V摩耗試験後の擬似体液より細胞増殖を阻害した。ミリポアフィルターでのろ別により細胞増殖はやや改善したが、完全には回復しなかった。擬似体液中への金属イオンの溶出量はUHMWPE-アルミナの場合Al:0.5μg/ml、UHMWPE-窒化鍛造Ti-6Al-4Vの場合Ti: <0.1μg/mlであった。一方AlCl₃及びAl(OH)₃溶液はAl:0.3μg/ml(飽和濃度)まで細胞増殖の阻害は認められなかった(4日後の溶液中の細胞数/4日後のコントロール中の細胞数=0.96)。PSZ、HAPについてもアルミナと同様の結果が得られた。

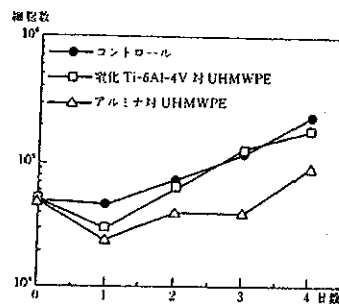


図 窒化Ti-6Al-4V、およびアルミナ対UHMWPEの摩耗試験後の擬似体液を加えた培地中でのL929細胞の増殖曲線