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髖臼杯內襯磨耗型態與體積方程式之探討並解析多向磨耗之發生機制

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□期中進度報告

髖臼杯內襯磨耗型態與體積方程式之探討並解析多向磨耗之發生機制

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共同主持人：
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中 華 民 國 99 年 10 月 05 日

具柱狀延伸部之髖臼杯內襯磨耗分析
WEAR ANALYSIS for CYLINDRICALLY ELONGATED ACETABULAR CUP LINERS

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一、中文摘要

本研究探討具有柱狀延伸部之髖臼杯內襯之磨耗形態與體積缺損量理論公式。首先，將不同方向造成的磨耗型態予以分類，再推導各類別之體積缺損量方程。藉由 SolidWorks®軟體以及文獻上之公式驗證分析之正確性。結果顯示，包括正向磨耗(90°)的特例在內，此類髖臼杯共有七種磨耗型態。而且，為了避免人工股骨頭脫臼所給予的髖臼杯杯口延伸部將產生可觀的磨耗碎粒，隨著磨耗方向與延伸部高度的變化，在本文所探討的例子中最高可達 21%。本研究的提出將有助於臨床使用成效之正確評估以及人工髖關節組件的設計分析。

關鍵詞：磨耗、髖臼杯、內襯、聚乙烯

Abstract

This study analyzed the wear patterns of, and wear volume formulae for, cylindrically elongated acetabular cup liners. The geometric patterns of the wear surface were first classified, then wear volume formulae were derived by integral calculus. SolidWorks® software or published formulae were used to verify the accuracy of the proposed formulae. The analytical results showed that the wear shape of the liner can be categorized into seven wear patterns, including the special case of wear at 90°, and the seven corresponding wear formulae were derived. In addition, wear of the cylindrical elongation might add considerably to the volume loss of the liner, depending on the height and shape of the elongation and the depth and direction of the linear penetration, being maximally 21% in the investigated model. The proposed wear formulae and patterns will be useful for more accurate performance evaluation of existing hip components implanted in patients and for the designing of new hip components.

Keywords: Wear, Acetabular Cup, Liner, UHMWPE

二、緣由與目的(Introduction)

Tiny ultra-high molecular weight polyethylene (UHMWPE) debris generated by long-term friction between the artificial femoral head and the acetabular cup is known to reduce the longevity of total hip replacements [1-3].

In the past, femoral head displacement has usually been regarded in terms of liner wear depth [4]. Many studies have analyzed 2D and 3D linear wear [5-8] and focused on the calculation of the acetabular cup volume loss [9-16]. Charnley [9] first stated that the wear volume could be calculated as the maximal cross-sectional area of the femoral head multiplied by the wear depth. However, Kabo [10] reported that the wear volume should not be based solely on wear depth, but also on the direction of femoral head movement. Nevertheless, some studies [13, 15] pointed out that the Kabo formula produced errors as high as 45%. Recently, Ilchmann et al. [16] compared several published formulae and proposed a new formula, which, however, has been found not to be sufficiently accurate [17]. The aim of this study was therefore to obtain a more accurate formula.

Although acetabular cup liner loss is due to wear, creep, and/or the effects of the ageing of polyethylene [18-21], the present study did not attempt to distinguish between these different causes, but instead analyzed the shape of the bearing surface and the volume loss of worn regions at a given wear depth and direction. Once wear patterns are clearly clarified, related studies, such as gait simulation and stress analysis, can be more accurately performed. To be consistent with commonly used terminology, the volume calculated was the total volume loss, which is due to the effects of both wear and creep.

三、材料與方法(Materials and Methods)

Figure 1 is a basic diagram showing the geometric structure of an acetabular cup liner and the trajectory of femoral head movement. The liner is formed from a hemispherical shell and a cylindrical elongation (Fig. 1a). The length of the elongation is denoted as D. The hemispherical shell and artificial femoral head (Fig. 1b) have the same radius, r. The trajectory of the femoral head that penetrates the PE liner is assumed to be translational motion [9], and the displacement of the center of the femoral head, $\overline{oo'}$, is given by the wear depth, w [4]. The dashed and solid lines in Fig. 1b denote the starting and final position of the femoral head, respectively, and the arrow shows the direction of femoral head penetration. The maximal circular section of the femoral head, which is perpendicular to the penetration direction, translates from dc to ab. Both $\overline{da}$ and $\overline{cb}$ are line segments.

A. Observation and classification of wear patterns

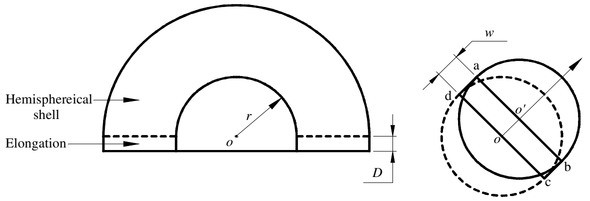

Fig. 1 Basic diagram. (a) Structure of a cylindrically elongated liner. (b) Trajectory of femoral head movement. $\overline{\mathrm{da}}$ and $\overline{\mathrm{cb}}$ are line segments.

Figure 2 presents the wear models, constructed using SolidWorks® software, of a cylindrically elongated liner at various wear depths. The left panels show frontal views of the wear patterns. In each diagram, the two oblique lines represent the cylindrical wear trajectory, abcd (Fig. 1b), and the distance between the two oblique lines is the wear depth, *w*. The dashed circles show the differences in the wear patterns. When the wear depth is less than the length of the elongation (Fig. 2a), the wear area of the cylindrical elongation is bounded by a curved line and a line segment. The curved line is the intersection of the femoral head surface ab (Fig. 1b) and the cylindrical elongation, while the line segment is the intersection of the femoral head trajectory abcd (Fig. 1b) and the cylindrical elongation. When the wear depth is equal to (Fig. 2b), or larger than (Fig. 2c), the length of the elongation, the wear area of the cylindrical elongation is bounded by a line segment. The right panels show 3D views of the wear models.

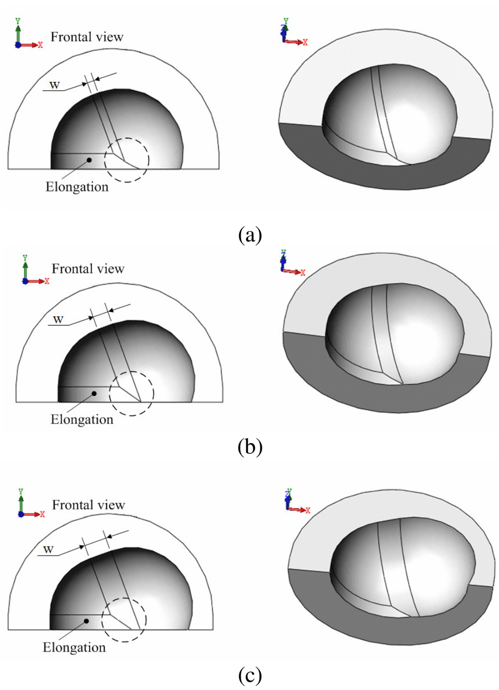

Fig. 2 Wear surfaces of an acetabular cup liner constructed using SolidWorks®. (a) to (c) Wear patterns (represented as dashed circles) as the wear depth increases. The diagrams on the left are frontal views and those on the right perspective views.

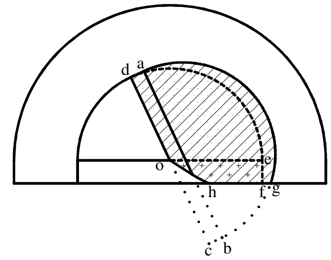

Fig. 3 Conceptual model for calculating the wear volume.

B. Computation of the wear volume

The liner volume loss associated with all wear patterns can be obtained by subtracting the dotted region and crossed region from the striped region by integration (Fig. 3).

C. Validation I: SolidWorks® 3D wear models

SolidWorks® software was used to create models of the worn out regions of liners at various wear directions and depths [17].

D. Criteria for determining accuracy of formulae

The wear volume, V_W, at any direction and any depth had to meet the criteria proposed in our previous paper [17].

四、結果(Results)

For a cylindrically elongated liner with radius *r* and elongation length *D*, when the wear depth is *w* and the wear angle β, the wear pattern and corresponding wear formula are determined from the decision-making flowchart (Fig. 4).

The wear formulae $V_{W,A}$ to $V_{W,F}$ and that of the special pattern of a wear angle of 90°, $V_{W,90}$, please refer to our published paper [22].

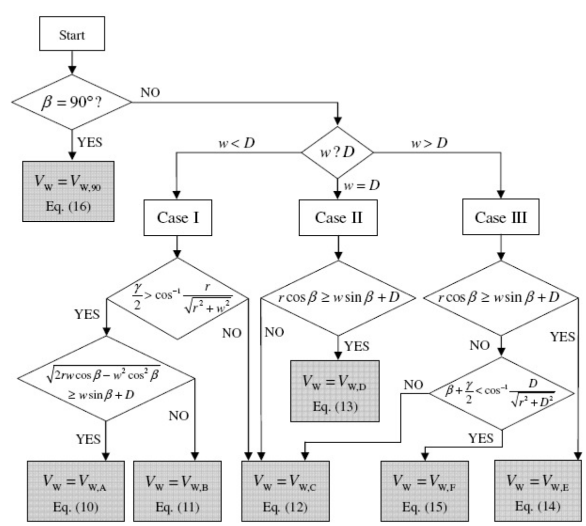

Fig. 4 Decision-making flowchart for classifying wear patterns

Figure 5 shows that the volumes of 60 worn out region models generated by SolidWorks® were close to the wear volumes calculated using the proposed formulae. The maximal difference was about 0.04% (wear angle 20° and wear depth 1mm). All the wear volumes calculated using the proposed formulae satisfied the criteria proposed in our previous paper [17].

Except where stated otherwise, the diameter of the liner was 32 mm and the length of the cylindrical elongation 4 mm. Figure 6 compares the results obtained using the proposed formulae with those obtained using published formulae for a wear depth of 5 mm. The curve developed by Ilchmann is closest to that obtained using the proposed formulae; however, when the wear angle was 40–90°, the wear volume exceeded the maximal value, V_{max} . For detailed comparisons and discussions, please refer to Wu [17].

Figure 7 shows the percentage difference between the results obtained using the Ilchmann formula and the proposed formulae. The values obtained using the Ilchmann formula exceeded those yielded by the proposed formulae; when the wear depth was 5.0 or 1.0 mm, the maximal difference was about 6% or 12%, respectively.

Figure 8 plots the wear volume curves for liners with and without a cylindrical elongation (D = 4 mm *vs.* D = 0 mm) at a wear depth of 5 mm. The solid curve represents the wear volume of a hemispherical liner (without elongation) and the space between the solid curve and dashed curve represents the wear of the elongation. Figure 9 shows the wear of the cylindrical elongation expressed as a percentage of the total wear volume. When the wear angle was varied from 0° to 70°, this percentage declined in a near-linear fashion from about 21% to 0%. When the wear angle exceeded 70°, the cylindrical elongation remained almost intact and all of the wear was associated with the hemispherical shell.

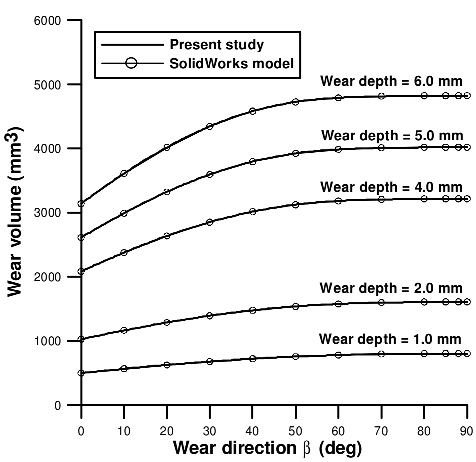

Fig. 5 Comparison of wear volumes obtained using the proposed formulae and those obtained using SolidWorks® for a liner diameter of 32 mm.

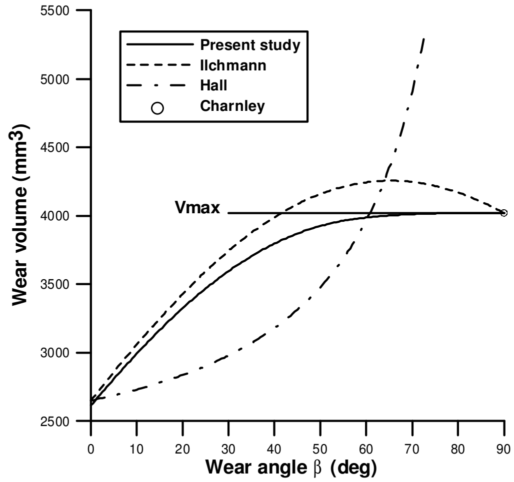

Fig. 6 Comparison of values obtained using the proposed formulae with those given by published formulae at a liner diameter of 32 mm and wear depth of 5 mm.

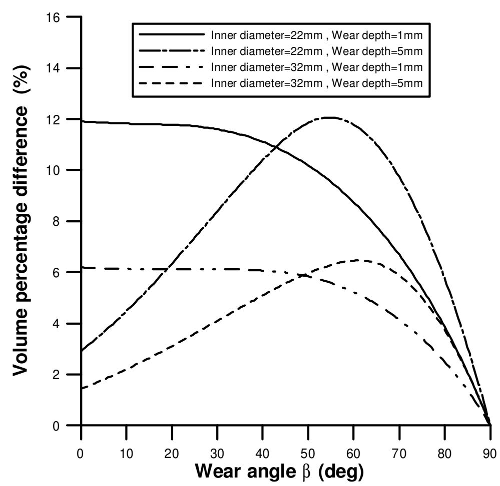

Fig. 7 Compared to the values obtained in this study, wear volumes are overestimated using the Ilchmann formula (maximal difference of about 12%).

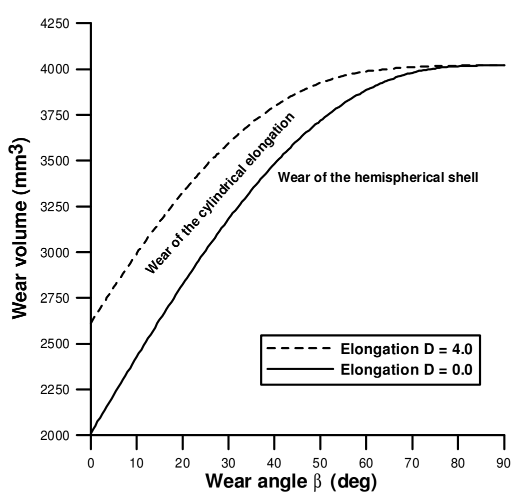

Fig. 8 Wear volume curves for liners with or without a cylindrical elongation at a wear depth of 5mm. The space between the solid line and dashed line represents the wear of the elongation.

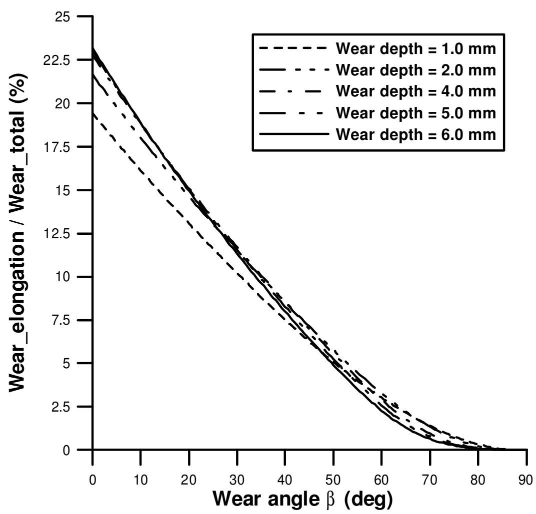

Fig. 9 Wear of the cylindrical elongation as a percentage of the total wear volume at various wear depths.

五、討論(Discussion)

This study is a thorough theoretical reflection on all geometrical aspects of wear volume calculations for acetabular cup liners with ($D > 0$) or without ($D = 0$) an elongation. The derivations were based on the assumption that the trajectory of the femoral head that penetrates the liner is translational motion [9, 4]. To obtain accurate results for the performance of bearings using the presented formulae, it is assumed that the wear vector has been accurately measured, as in other studies [9, 11, 16, 17].

Many forms of liners, such as hard-on-hard bearings (metal-metal, ceramic-ceramic) or hard-on-soft bearings (metal-PE, ceramic-PE) are used in the clinic. For hard-on-hard bearings, several authors have discussed the effects on wear of impingement or microseparation during gait [23-27]. The limitations and benefits of contemporary combinations of hip bearings have been comprehensively illustrated by Clarke et al. [25]. Besong et al. [28] reported that microseparation significantly raises the contact stress, which becomes concentrated in the contact region of the superolateral rim of the cup, including the edge of the opening, and that microseparation will accelerate wear [24, 29]. However, Ingham et al. [3] deemed that the volumetric concentration of the particles is unlikely to achieve the threshold needed in vivo to induce osteolytic cytokine production. In general, for hard-hard bearings, the wear is extremely low and it is therefore almost impossible to measure the linear penetration and direction of wear on radiographs, and volume measurements can probably only be made from retrieved cups. However, when the volume of the retrieved liner cannot be accurately measured, for example, if there are adherent tissues or surgical scratches, numerical methods may be an alternative if the linear penetration can be accurately measured. Almost all hard-on-hard bearings are exactly hemispherical. In this case, the elongation length D in the presented formulae is set as 0.

For hard-on-soft bearings, the boundaries of the PE liner on radiographs have normally been recognized and processed by image-processing technologies [5, 12, 30, 7, 8]. Several authors have adopted computer-assisted measurement systems or commercial software to assess 2D or 3D wear vectors from radiographs [31-34]. However, some factors, such as the radiolucence of the PE, the obliqueness, irregularity, or asymmetry of the edges of the PE, the rough surface of the cup, and the lack of sharpness and distortion in the X-ray image of the cup, influence the accurate evaluation of a wear vector, and multiple wear vectors have even been found in retrieved implants [35]. Other limitations are that the elongation might not be cylindrical, but conical or only partially cylindrical, and the exact shape or orientation of a partial elongation cannot be seen on radiographs. Though Sychterz et al. [32] pointed out that, for most patients, head penetration can be measured sufficiently accurately from the anteroposterior radiograph alone, Devane et al. [30] reported that interpretation of this femoral head penetration as true PE wear may be erroneous. Under these conditions, this study calculated the main wear volume generated by the linear penetration, which can be measured on radiographs. Furthermore, there is usually a clearance between the head and the cup, which may influence the estimation of theoretical wear volume. Derbyshire [13] found that, at small wear depths (<0.2 mm), neglecting a radial discrepancy between the components can result in an overestimation of wear volume in excess of 100%. However, in the clinic, if the linear penetration is very low, the worn PE particles are no problem. In contrast, if we want to calculate wear volumes at a significant linear wear [36], then this overestimation phenomenon decays rapidly with increasing wear depth [13]. For this reason, this study and other published studies [9, 10, 12, 14, 16] did not consider the effect of clearance.

Currently used cups are frequently strictly hemispherical and the edges in the entrance plane oblique to increase the range of motion. In this study, to simplify formula derivation and to understand the effect of the elongation on the amount of wear, a cylindrical elongation without a conical chamfer was considered. In this case, the wear of the cylindrical elongation as a percentage of the total wear was about 21% at a wear angle of 0° and decreased almost linearly to 0% at a wear angle of 70°. When the wear angle exceeded 70°, the cylindrical elongation remained almost intact._It must be noted that the wear of the cylindrical elongation depends on the height and shape of the elongation and the amount and direction of linear penetration. It may be further inferred that, when the edges in the entrance plane are oblique, as in currently used cups, the percentage of wear represented by wear of the elongation should be decreased.

Derbyshire [13] published the theoretical determination of wear volume using numerical integration techniques, but no wear patterns or wear formulae were presented and the results were therefore hard to assess. Furthermore, the results were not validated.

This study used the methods proposed in our previous paper [17] and verified that the proposed formulae and wear shapes are very accurate and reliable. The proposed formulae can be easily written as a computer program using Gaussian integration for clinical applications or implant designs. This work is the first to present all of the wear patterns and the wear volume formulae for acetabular cup liners with or without an elongation and provides a deeper understanding of the complex theory of wear volume calculation after total hip replacement. Bennett et al. [37] pointed out that pre-clinical laboratory wear testing of joint replacements is a vital evaluation tool for new implant materials and designs. Clarke et al. [25] also deemed that the role of laboratory studies is to isolate relevant aspects of performance by cup design. One alternative approach to experimental wear studies is computational modeling involving finite element analysis [38-40]. Recently, Matsoukas et al. [41] performed a mathematical optimization of implant components using a validated computational volumetric wear model as an objective function and concluded that the use of validated performance metrics as objective functions is possible in the optimization of total hip replacement prostheses.

Any method for calculating the wear volume, including that used in our previous study [22] and here, is based on the assumption that the wear vector can be accurately measured. Although there might be some limitations in the accurate determination of the wear volume, the mathematic calculations using our method are correct and the proposed formulae have been shown to be the most accurate available. In this study, the wear surface of a cylindrically elongated liner was classified as one of seven wear patterns and the seven corresponding wear formulae were derived.

We conclude that the use of a single formula to calculate the wear volume of an acetabular cup liner with a cylindrical elongation is not satisfactory. The proposed wear formulae and patterns will be useful in designing new hip components. Furthermore, an accurate calculation of the wear volume is also important in order to obtain a better understanding of loosening and osteolysis of cups made from conventional PE and probably those made from the modern highly crosslinked PE [42, 43, 3].

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七、參考文獻(References)

[1] C. H. Shih, P. C. Lee, J. H. Chen, et al., "Polyethylene wear in cementless total hip arthroplasty," *J. Bone Joint Surg. Br.*, 79(3):361-5, (1997).

[2] J. H. Dumbleton, M. T. Manley and A. A. Edidin, "A literature review of the association between wear rate and osteolysis in total hip arthroplasty," *J. Arthroplast.*, 17(5):649-61, (2002).

[3] E. Ingham and J. Fisher, "The role of macrophages in osteolysis of total joint replacement," *Biomaterials*, 26(11):1271-86, (2005).

[4] J. Livermore, D. Ilstrup and B. Morrey, "Effect of femoral head size on wear of the polyethylene acetabular component," *J. Bone Joint Surg. Am.*, 72:18-28, (1990).

[5] J. R. Hernandez, E. M. Keating and P. M. Faris, "Polyethylene wear in uncemented acetabular components," *J. Bone Joint Surg. Am.*, 70:257-67, (1988).

[6] T. Ilchmann, B. Mjoberg and H. Wingstrand, "Measurement accuracy in acetabular cup wear. Three retrospective methods compared with Roentgen stereophotogrammetry," *J. Arthroplast.*, 10:636-42, (1995).

[7] J. M. Martell, S. S. Leopold and X. Liu, "The effect of joint loading on acetabular wear measurement in total hip arthroplasty," *J. Arthroplast.*, 15:512-8, (2000).

[8] J. H. Chen and J. S. S. Wu, "Measurement of polyethylene wear: a new three-dimensional methodology," *Comput. Methods Prog. Biomed.*, 68(2):117-27, (2002).

[9] J. Charnley, A. Kamangar and M. D. Longfield, "The optimum size of prosthetic heads in relation to the wear of plastic sockets in total replacement of the hip," *Med. Biol. Eng.*, 7:31-9, (1969).

[10] J. M. Kabo, J. S. Gebhard, G. Loren, et al., "In vivo wear of polyethylene acetabular components," *J. Bone Joint Surg. Br.*, 75(2):254-8, (1993).

[11] R. M. Hall, A. Unsworth, P. S. Craig, et al., "Measurement of wear in retrieved acetabular sockets," *Proc. Inst. Mech. Eng. Part H.*, 209:233-42, (1995).

[12] Y. Hashimoto, T. W. Bauer, M. Jiang, et al., "Polyethylene wear in total hip arthroplasty: volumetric wear measurement of retrieved acetabular components.," *Trans. Orthop. Res. Soc.*, 20:116, (1995).

[13] B. Derbyshire, "The estimation of acetabular cup wear volume from two-dimensional measurements: a comprehensive analysis," *Proc. Inst. Mech. Eng. Part H.*, 212:281-91, (1998).

[14] R. Košak, V. Antolic, V. Pavlovcic, et al., "Polyethylene wear in total hip prostheses: the influence of direction of linear wear on volumetric wear determined from radiographic data," *Skeletal Radiol.*, 32(12):679-86, (2003).

[15] T. Mizoue, K. Yamamoto, T. Masaoka, et al., "Validation of acetabular cup wear volume based on direct and two-dimensional measurements: hip simulator analysis " *J. Orthop. Sci.*, 8(4):491-9, (2003).

[16] T. Ilchmann, M. Reimold and W. Müller-Schauenburg, "Estimation of the wear volume after total hip replacement.

A simple access to geometrical concepts," *Med. Eng. Phys.*, 30(3):373-9, (2008).
[17] J. S. S. Wu, S. L. Hsu and J. H. Chen, "Evaluating the accuracy of wear formulae for acetabular cup liners," *Med. Biol. Eng. Comput.*, 48(2):157-65, (2010).
[18] H. A. Mckellop, P. Campbell and S. H. Park, "The origin of submicron polyethylene wear debris in total hip arthroplasty," *Clin. Orthop. Rel. Res.*, 311:3-20, (1995).
[19] C. J. Sychterz, K. H. Moon, Y. Hashimoto, et al., "Wear of polyethylene cups in total hip arthroplasty. A study of specimens retrieved post mortem," *J. Bone Joint Surg. Am.*, 78:1193-200, (1996).
[20] B. Rammamurti, D. M. Estok, C. R. Bragdon, et al., "Dimensional changes in metal-backed polyethylene acetabular cups under cyclic loading," *Trans. Orthop. Res. Soc.*, 24:822, (1999).
[21] S. L. Bevill, G. R. Bevill, J. R. Penmetsa, et al., "Finite element simulation of early creep and wear in total hip arthroplasty," *J. Biomech.*, 38:2365-74, (2005).
[22] J. S. S. Wu, S. L. Hsu and J. H. Chen, "Wear patterns of, and wear volume formulae for, cylindrically elongated acetabular cup liners," *Med. Biol. Eng. Comput.*, 48(7):691-701, (2010).
[23] A. V. Lombardi, T. H. Mallory, D. A. Dennis, et al., "An in vivo determination of total hip arthroplasty positioning during activity," *J. Arthroplast.*, 15(6):702-9, (2000).
[24] T. Stewart, J. Tipper, R. Streicher, et al., "Long-term wear of HIPed alumina on alumina bearings for THR under microseparation conditions," *J. Mater. Sci. Mater. Med.*, 12(10-12):1053-6, (2001).
[25] I. C. Clarke and M. T. Manley, "How do alternative bearing surfaces influence wear behavior," *J. Am. Acad. Orthop. Surg.*, 16(S1):S86-S93, (2008).
[26] K. Hara, N. Kaku, H. Tsumura, et al., "Analysis of wear and oxidation on retrieved bipolar polyethylene liner," *J. Orthop. Sci.*, 13:366-70, (2008).
[27] I. C. Clarke, D. D. Green, P. A. Williams, et al., "Hip-simulator wear studies of an alumina-matrix composite (AMC) ceramic compared to retrieval studies of AMC balls with 1-7 years follow-up," *Wear*, 267:702-9, (2009).
[28] A. Besong, Z. M. Jin and J. Fisher, Analysis of micro-separation and contact mechanics between the femoral head and the acetabular cup in artificial hip joint replacements, 47th annual meeting of the orthopaedic research society (2000) p 1051.
[29] S. Williams, M. Butterfield, T. Stewart, et al., "Wear and deformation of ceramic-on-polyethylene total hip replacements with joint laxity and swing phase microseparation," *Proc. Inst. Mech. Eng. Part H.*, 217(2):147-53, (2003).
[30] P. A. Devane and J. G. Horne, "Assessment of polyethylene wear in total hip replacement," *Clin. Orthop. Rel. Res.*, 369:59-72, (1999).
[31] C. J. Sychterz, C. A. J. Engh, A. Yang, et al., "Analysis of temporal wear patterns of porous-coated acetabular components: distinguishing between true wear and so-called bedding-in," *J. Bone Joint Surg. Am.*, 81(6):821-30, (1999).
[32] C. J. Sychterz, A. M. Yang, J. P. McAuley, et al., "Two-dimensional versus three-dimensional radiographic measurements of polyethylene wear," *Clin. Orthop. Rel. Res.*, 365:117-23, (1999).
[33] X. Dai, H. Omori, Y. Okumura, et al., "Serial measurement of polyethylene wear of well-fixed cementless metal-backed acetabular component in total hip arthroplasty: an over 10 year follow-up study," *Artif. Organs*, 24(9):746-51, (2000).
[34] C. J. Sychterz, C. A. J. Engh, A. M. Young, et al., "Comparison of in vivo wear between polyethylene liners articulating with ceramic and cobalt-chrome femoral heads," *J. Bone Joint Surg. Br.*, 82(7):948-51, (2000).
[35] M. Yamaguchi, T. W. Bauer and Y. Hashimoto, "Three-dimensional analysis of multiple wear vectors in retrieved acetabular cups," *J. Bone Joint Surg. Am.*, 79(10):1539-44, (1997).
[36] J. E. Dowd, C. J. Sychterz, A. M. Young, et al., "Characterization of long-term femoral-head-penetration rates," *J. Bone Joint Surg. Am.*, 82(8):1102-7, (2000).
[37] D. Bennett, L. Humphreys, S. O'Brien, et al., "Wear paths produced by individual hip-replacement patients - a large-scale, long-term follow-up study," *J. Biomech.*, 41:2474-82, (2008).
[38] J. S. S. Wu, J. P. Hung, C. S. Shu, et al., "The computer simulation of wear behavior appearing in total hip prosthesis," *Comput. Methods Prog. Biomed.*, 70(1):81-91, (2003).
[39] J. C. Fialho, P. R. Fernandes, L. Eca, et al., "Computational hip joint simulator for wear and heat generation," *J. Biomech.*, 40(11):2358-66, (2007).
[40] L. Kang, A. L. Galvin, J. Fisher, et al., "Enhanced computational prediction of polyethylene wear in hip joints by incorporating cross-shear and contact pressure in additional to load and sliding distance: effect of head diameter," *J. Biomech.*, 42:912-8, (2009).
[41] G. Matsoukas and I. Y. Kim, "Design optimization of a total hip prosthesis for wear reduction," *J. Biomech. Eng.*, 131(5):051003(1-12), (2009).
[42] M. D. Ries, M. L. Scott and S. Jani, "Relationship between gravimetric wear and particle generation in hip simulators: conventional compared with cross-linked polyethylene," *J. Bone Joint Surg. Am.*, 83-S2(2):116-22, (2001).
[43] V. Saikko, O. Calonius and J. Keranen, "Wear of conventional and cross-linked ultra-high molecular weight polyethylene acetabular cups against polished and roughened CoCr femoral heads in a biaxial hip simulator," *J. Biomed. Mater. Res.*, 63:848-53, (2002).

國科會補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

■ 達成目標

□ 未達成目標（請說明，以 100 字為限）

□ 實驗失敗

□ 因故實驗中斷

□ 其他原因

說明：

2. 研究成果在學術期刊發表或申請專利等情形：

論文：■已發表 □未發表之文稿 □撰寫中 □無

專利：□已獲得 □申請中 □無

技轉：□已技轉 □洽談中 □無

其他：（以 100 字為限）

J. S. S. Wu, S. L. Hsu and J. H. Chen, "Wear patterns of, and wear volume formulae for, cylindrically elongated acetabular cup liners," *Med. Biol. Eng. Comput.*, 48(7):691-701, (2010). (SCI, IF:1.757, Ranking: 26/95, 27.4%)

3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）（以 500 字為限）

本系列之研究提出髖臼杯磨耗的分析方法和驗證方法，且進一步將臨床常用髖臼杯的磨耗分析理論方程推導出來，並撰寫為電腦程式，有助於對該類髖臼杯之臨床使用成效達成正確之評估，並且對後續新式人工髖關節的組件設計提供一正確的分析工具。本系列之研究已經在國際期刊上發表三篇論文，在此領域上具有領先之成果，總 Impact Factor 點數達 5.285 點。

無研發成果推廣資料

98 年度專題研究計畫研究成果彙整表

計畫主持人：陳建宏	計畫編號：98-2221-E-040-003-
計畫名稱：髖臼杯內襯磨耗型態與體積方程式之探討並解析多向磨耗之發生機制	

成果項目			量化			單位	備註（質化說明：如數個計畫共同成果、成果列為該期刊之封面故事...等）
			實際已達成數（被接受或已發表）	預期總達成數(含實際已達成數)	本計畫實際貢獻百分比		
國內	論文著作	期刊論文	0	0	100%	篇	
		研究報告/技術報告	0	0	100%		
		研討會論文	1	0	100%		
		專書	0	0	100%		
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（本國籍）	碩士生	0	0	100%	人次	
		博士生	1	0	100%		
		博士後研究員	1	0	100%		
		專任助理	0	0	100%		
國外	論文著作	期刊論文	1	0	100%	篇	
		研究報告/技術報告	0	0	100%		
		研討會論文	0	1	100%		
		專書	0	0	100%	章/本	
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（外國籍）	碩士生	0	0	100%	人次	
		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		

其他成果 (無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。)	無

	成果項目	量化	名稱或內容性質簡述
科教處計畫加填項目	測驗工具(含質性與量性)	0	
	課程/模組	0	
	電腦及網路系統或工具	0	
	教材	0	
	舉辦之活動/競賽	0	
	研討會/工作坊	0	
	電子報、網站	0	
	計畫成果推廣之參與（閱聽）人數	0	

國科會補助專題研究計畫成果報告自評表

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　　□其他原因

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專利：□已獲得 □申請中 ■無

技轉：□已技轉 □洽談中 ■無

其他：（以 100 字為限）

論文發表於 Medical &； Biological Engineering &； Computing, 48(7):691-701, (2010).

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