行政院國家科學委員會專題研究計畫 成果報告

向前跌倒策略對上肢關節影響的生物力學分析與模擬
研究成果報告(精簡版)

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行政院國家科學委員會補助專題研究計畫 ■ 成果報告
□期中進度報告

向前跌倒策略對上肢關節影響的生物力學分析與模擬

計畫類別：■ 個別型計畫　　□ 整合型計畫
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計畫主持人：羅世忠　中山醫學大學　職能治療學系
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計畫參與人員：卓旻賢　徐振凱　　朝陽科技大學工業工程與管理系

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中　華　民　國　95　年　12　月　29　日

行政院國家科學委員會專題研究計畫成果報告

向前跌倒策略對上肢關節影響的生物力學分析與模擬

Biomechanical analysis and simulation of upper extremity during forward falls

計劃編號：NSC 94-2614-E-040-003
執行期限：：94 年08 月01 日至95 年9月30 日

計畫主持人：羅世忠中山醫學大學 職能治療學系
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一、摘要

向前跌倒一直是造成上之肌肉骨骼系統嚴重傷害的主要原因之一，也是生物力學研究學者極力了解與避免傷害的重要領域之一。一般評估向前跌倒造成傷害的生物力學因子可分為兩項，一是引起上肢受力的地面衝擊力，二是肌肉骨骼系統能夠承受的關節力。而人體的承受力為個體特徵無法在跌倒時期改變，但是從許多的研究報告發現，地面衝擊力與上肢姿勢的改變有明顯關係，但還未明朗。

因此，本研究計畫以以 10 位無肌肉骨骼方面疾病之年輕人,使用 3D 動作分析系統(包括 Vicon460 與 AMTI)，比較 2 種不同手肘策略，包含手臂伸直、手臂自然彎曲、與跌落高度，4 公分與 8 公分在向前跌倒時，對上肢關節受力之影響，並將實驗結果建立人體動作分析模擬軟體 Adams-LifeMOD 之模擬模型，以便預測複雜策略與較高之高度跌落時，對上肢關節之影響，求得降低向前跌到所造成的上肢傷害之較佳策略。

實驗結果發現跌落高度增加，各狀態之地面反作用之峰值、肘關節之三軸力量與肘關節內外展力矩皆明顯增加。跌落時手臂自然彎曲能減少第一峰值，並且能延遲第一峰值發生時間，並且手臂彎曲時屈曲伸展力矩與內外轉力矩明顯大於手臂伸直之值。在ADAMS LifeMOD 模擬結果發現，向前跌倒之手臂伸直與手臂彎曲與實驗值在地面反作用力接近，但是模擬值較實驗值陡峭，變化趨勢發生時間提前。

所以本研究之結論為降低跌落高度、使用手臂彎曲策略運用，可以降低地面衝擊力，達到減少上肢傷害。而合適的肌肉骨骼特性資料使軟體模擬可以有效接近實驗值。

關鍵詞：向前跌倒、生物力學、逆向動力學

Abstract

A forward fall is the most common cause of server upper extremity injury. Biomechanical investigators desire to know how to decrease the injury. Two main biomechanical factors determine the severity of injury: the impact force and the resistance to injury of the body tissues loaded by joint forces and moment. The capability of resistance can not be changed easily at impact. The impact force, from many studies, showed significant change with various posture of upper extremity, but not clear.

This project is to understanding the effect of the strategies, elbow extended and flexed, fall height, 4cm and 8 cm, on impact force and loading of upper extremity by motion analysis and simulation model. Ten physically healthy male subjects is recruited for this investigation. None had ever suffered from upper extremity injuries or disorders. Motion analysis system (Vicon460 and ATMI) is used to measure relative joint positions and ground reaction forces. Subjects are released unexpectedly to perform forward falls from releasing system with four flexion postures of elbow—outstretched, self-initialed, flexed 30 degrees and 60 degrees. The kinematic and kinetic data of the elbow among postures are analyzed statistically. The human motion simulation software, ADAMS LifeMOD, is used to build the biomechanical model by the coordinate of markers for understanding the role of the skeletal system during complex forward falls. The model is modified to be prefect by comparing the joint forces and moment calculated from simulated model with those from experimental results.

The results of this study were as follows. The impact force, loading rate, peak value of peak joint forces of elbow and abduction moment significantly increased as the increase of fall height. The strategy of elbow flexed could attenuate the peak GRF and delay the time of peak impact force. The extension moment of elbow in elbow flexed significantly increased than that in elbow extended. The result of ground reaction force on simulated model was the close to that on experiment, But the onset and slope of ground reaction force on simulated model were different than those on experiment.

The conclusion is that lower falling height, using the strategy of elbow flexed will decrease the impact force and the risk of injury of upper extremity. The simulated model can be fitted efficiently to experimental data by using the proper musculoskeletal properties.

Keyword: Forward falls, biomechanics, inverse dynamic method

二、緣由與目的

向前跌倒一直是造成上之肌肉骨骼系統嚴重傷害的主要原因之一，也是生物力學研究學者極力了解與避免傷害的重要領域之一[1-3]。向前跌倒時身體的自然反應會伸出手臂撐住地面，以避免身體直接撞擊

到地面，此作用在手臂上的撞擊力使得上肢產生嚴重傷害[2, 4-6]。向前跌到最常發生於孩童與老年族群中，由於社會年齡層的老化，反應慢的老年人產生向前跌倒受傷的比例亦大幅增加，另外，溜冰與滑板等劇烈運動中向前跌倒一直都是常見，尤其是對於初學者[7, 8]，通常會採用手臂伸直(outstretched hand)策略對應，則有 90%的骨折會發生在手肘的遠側橈骨(distal radius)，肱骨頸部(humeral neck)與上髁脊等部位。反之，如果手肘若是彎曲 80 度則容易造成橈骨頭(radial head)與喙狀突(coronoid)的骨折，鷹嘴(olecranon)骨折則常發生在手肘彎曲 90 度時。而掌骨骨折則會因著地時手腕在背屈彎曲(dorsiflexion)，旋後(supination)與尺側偏向(ulnar deviation)的程度不同而造成不同的掌骨骨折[2, 9-11]。

評估向前跌倒造成傷害的生物力學因子可分為兩項，一是引起上肢受力的地面衝擊力，二是肌肉骨骼系統能夠承受的關節力，亦可以說向前跌倒的傷害風險可以簡化為地面衝擊力對承受的關節力的比值[10]。

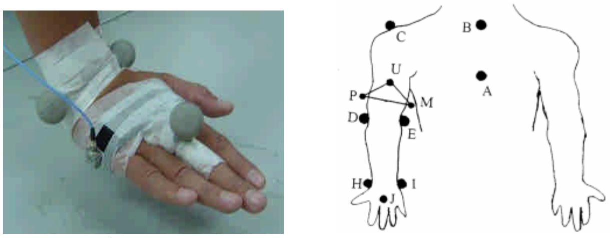
以地面衝擊力來說，向前跌倒過程主要分成 2 個階段，分別是撞擊前期(pre-impact)與撞擊期(impact)階段，2 個階段時程都相當的短，其中較長的撞擊前期階段或稱為下降階段，指的是由失去平衡到撞擊到地面這段時間，撞擊前期階段約為 0.7-1.0 秒，而在撞擊期階段撞擊後幾毫秒的時間內力量就由地板傳到身體接觸遠端，大約一百毫秒力量就由遠端傳至身體的近端，在這麼快的時間內，肌肉神經系統無法作出反應，對於抵抗跌倒並不能有實質上的改善。所以必須在撞擊前期階段設定好姿勢，這時的肌肉神經系統才能作出抵抗反應，而不是於撞擊期階段改變著地姿勢[6]。所以有許多研究想藉由了解撞擊前期階段以不同身體跌落策略，試圖減少跌倒時的地面衝擊力。

另外，就人體肌肉骨骼系統能夠承受的關節力量而言，許多相關研究發現向前跌倒時，上肢傷害的負載受到許多因素的影響，包括了骨骼外形尺寸、作用力點與負載方向等。一般而言，造成女性上肢傷害的的地面衝擊力量平均在 1580-3180N 之間，男性平均為 2370-3773 N 之間[4, 12]，並且發現前臂受傷部位通常發生於橈骨遠端，這些傷害通常發生於 8-10 毫秒之間[13]。不過這些資料都使來至於屍體的研究，在活體與屍體之間的反應是否相同仍然是未知議題。另外，許多學者發現骨質密度流失受到年齡的影響且造成骨頭強度縮減，雖然在追蹤 21 年的 3000 個案例中[9]，針對骨質密度特別照顧，但隨著年紀的增加，追蹤的案例中還是比年輕人的跌倒受傷發生率高出兩倍，因此傷害的造成與骨質密度雖有關，但並非是最直接造成傷害的原因。既然隨著年紀的增加，人體肌肉骨骼系統能夠承受的關節力量無法有效加強，那麼要如何減少地面衝擊力傷害的跌倒策略似乎是更形重要[10, 14]。

因此適時的在碰撞前期提供適合的跌倒策略對於減少向前跌倒所導致上肢、頭與軀幹受傷的想法是大多研究學者所知道的[11, 14-16]，但是由於實驗計算上的困難與複雜，許多研究僅僅就地面衝擊力的探討[16]，無法將上肢動作姿勢的運動學與動力學資料一併討論，或者簡化關節動作以 2D 情形表示[11]，但是不同的上臂跌落姿勢會影響上肢不同的受傷類別，尤其肘關節的姿勢中不僅僅只有 flexion/extension，還有 carry angle，因此有必要以完整的地面衝擊力配合 3D 動作姿勢，進一步分析手肘彎曲角度對地面衝擊力的影響，以及對上肢關節力的影響，其次為避免受測者傷害，過高的跌落高度或跌落時加上往前衝的速度，無法在實驗室中進行，必須配合電腦模擬軟體，將實驗中取得的人體參數，以多連桿的方式進行模擬，以獲得人體極限能力，避免人體進行相類似的運動，或提供輔具以避免嚴重傷害[17]。

三、方法

研究受測者為 10 位無肌肉骨骼方面疾病之年輕健康男性，年齡為 23 至 28 間，平均身高為 172.6 平均體重為 72.8 使用自製無線控制釋放架裝置，可以達到無預警釋放受測者，並以動作分析系統擷取置於人體上反光球空間中動作軌跡資料(Vicon Motion System 460)與測力板，收集地面反作用力(Model BP600900-6-1000 AMTI USA, 60cm*90cm)如圖 1(右)所示、反光球貼法如圖 1(左)所示。



A：第四胸椎(T4)
B：第七頸椎(C7)
C：肩峰
D：肱骨外側上
U、P、M：三角標記架
E：肱骨內側上髁
H：橈骨莖突
I：尺骨莖突
J：第三掌骨

圖 1　反光球貼法(背視)

實驗過程首先讓受測者穿上可調整的懸吊衣，以單手伏地挺身姿勢由釋放架吊起(受測者大腿與水平夾角為 30 度；手臂與垂直夾角為 15 度)。掉落高度以手掌離地 4cm 與 8cm，以隨機方式進行各狀態單手手臂伸直落下的實驗，手臂伸直姿勢是以手肘完全伸展與彎曲狀態著地； (如圖 2)。

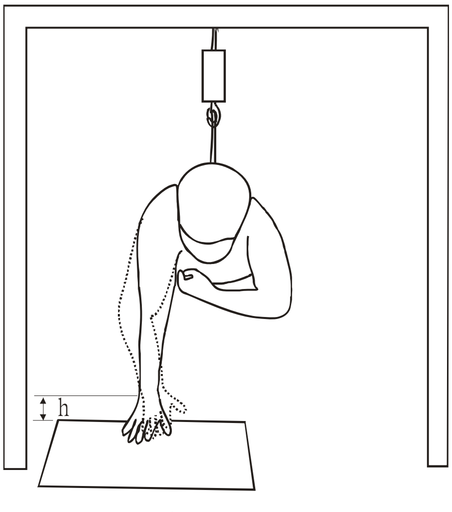


圖 2 實驗裝置圖

資料收集方面，動作分析系統以 120Hz 擷取受測者動作軌跡資料，並同步收集測力板資料(擷取頻率為 3000Hz)。

將動作分析所得到的反光球空間資料作為人體模型(圖 3)的已知，並參考 Chiu[18]之方式求得腕關節、肘關節與肩關節之彈簧常數與阻尼係數，以及加入肌肉模型，肌肉模型是以長度變化作為施力的函數。

	彈簧常數(KN/m)	阻尼係數(KN*s/m)
腕關節	28.5±4.2	0.6±0.2
肘關節	1.7±0.6	0.2±0.05
肩關節	2.5±1.6	0.31±0.06

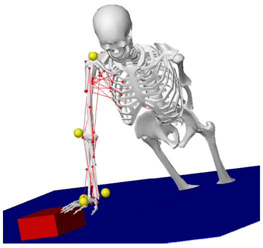


圖 3、向前跌倒之生物力學模型

四、結果

地面反作用力

在各種不同策略下，4 公分高度跌落之所有地面反作用力峰值皆與 8 公分高度跌落時量測之值有顯著差異。其中 4 公分手臂伸直赤手狀態之第一峰值平均為 84.35%BW(600N)，8 公分手臂伸直赤手狀態之第一峰值平均為 146.05%BW(1042N)，8 公分手臂伸直赤手狀態約比 4 公分手臂伸直赤手狀態增加 73%(圖 4)；4 公分手臂伸直赤手狀態之第二峰值平均為 75.6%BW(540N)，8 公分手臂伸直赤手狀態之第二峰值平均為 81.99%BW(586N)，8 公分手臂伸直赤手狀態約比 4 公分手臂伸直赤手狀增加 9%(圖 4)。

峰值產生時間方面，4 公分高度跌落之峰值產生時間皆與 8 公分高度跌落時量測之值有顯著差異。4 公分手臂伸直赤手狀態之第一峰值產生時間平均為 22.48ms；8 公分手臂伸直赤手狀態之第一峰值產生時間平均為 21.23 ms，8 公分手臂伸直赤手狀態約比 4 公分手臂伸直赤手狀態減少 5%(圖 5)；4 公分手臂伸直赤手狀態之第二峰值產生時間平均為 74.33ms；8 公分手臂伸直赤手狀態之第二峰值產生時間平均為 54.03ms，8 公分手臂伸直赤手狀態約比 4 公分手臂伸直赤手狀態減少 37%。。

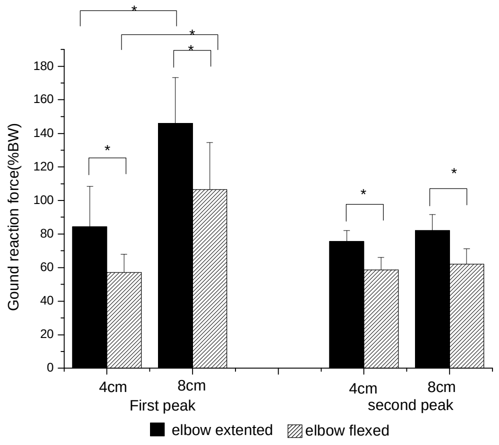


圖 4　地面反作用力在向前跌倒時之手臂伸直與彎曲與跌落高度 4 公分與 8 公分實驗結果

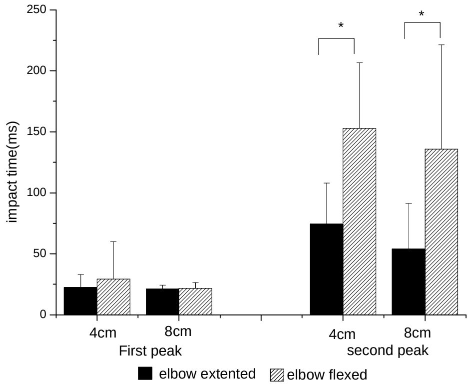


圖 5　第一峰值與第二峰值時間在向前跌倒時之手臂伸直與彎曲與跌落高度 4 公分與 8 公分實驗結果

肘關節動力學

跌落高度的影響:

關節力方面，在各種不同護腕支撐材質與策略下，8cm 高度跌落之肘關節三軸力量峰值皆與 4cm 高度跌落時量測之值有顯著差異(表一)。前後剪力方面，其中 4 公分手臂伸直赤手狀態之前後剪力為 12.91%BW(92.2N)，8 公分手臂伸直赤手狀態之前後剪力為 18.52%BW(132.3N)，8 公分手臂伸直赤手狀態約比 4 公分手臂伸直赤手狀態增加 43%。

內外剪力方面，4 公分手臂伸直赤手狀態之內外剪力為-22.58%BW (161.3N)，8 公分手臂伸直赤手狀態之內外剪力為-33.15%BW(236.7N)，8 公分手臂伸直赤手狀態約比 4 公分手臂伸直赤手狀態增加 46%。

軸向力方面，4 公分手臂伸直赤手狀態之軸向力為 80.35%BW(573.8N)，8 公分手臂伸直赤手狀態之軸向力為 113.35%BW(809.5N)，8 公分手臂伸直赤手狀態約比 4 公分手臂伸直赤手狀態增加 41%。

關節力矩方面，在各種不同護腕支撐材質與策略下，8cm 高度跌落之肘關節內外展力矩峰值皆與 4cm 高度跌落時量測之值有顯著差異，屈曲伸展力矩與內外轉力矩則無顯著差異(表二)，其中 4 公分手臂伸直赤手狀態之內外展力矩為 2.97%BW*arm (11.83Nm)，8 公分手臂伸直赤手狀態之內外展力矩為

6.43%BW*arm(25.62Nm)，8 公分手臂伸直赤手狀態約比 4 公分手臂伸直赤手狀態增加 116%。

手肘策略的影響:

關節力方面，在各種不同護腕支撐材質與跌落高度下，手臂伸直之肘關節三軸力量峰值皆與手臂彎曲量測之值有顯著差異(表一)。前後剪力方面，4 公分手臂彎曲赤手狀態之前後剪力為-13.7%BW(-97.8N)， 8 公分手臂伸直赤手狀態之前後剪力為-13.03BW (-93.05N)。

內外剪力方面，4 公分手臂彎曲赤手狀態之內外剪力為-27.58%BW (-192.8N)，4 公分手臂彎曲赤手狀態之內外剪力約比手臂伸直赤手狀態增加 19%，8 公分手臂彎曲之赤手狀態內外剪力為-36.83%BW (263.02N)，8 公分手臂彎曲赤手狀態約比手臂伸直赤手狀態增加 10%。

軸向力方面，4 公分手臂彎曲赤手狀態之軸向力為 54.03%BW(385.9N)，4 公分手臂彎曲赤手狀態軸向力約比手臂伸直赤手狀態減少 48%，8 公分手臂伸直赤手狀態之軸向力為 90.64%BW(647.32N)，8 公分手臂伸直赤手狀態約比手臂伸直赤手狀態減少 25%。

關節力矩方面，在各種不同護腕支撐材質與跌落高度下，手臂伸直之肘關節屈曲伸展力矩與內外轉力矩皆與手臂彎曲量測之值有顯著差異，但內外展力矩則無顯著差異(表二)，其中 4 公分手臂彎曲赤手狀態內外展力矩為 2.78%BW*arm (11.07Nm)，8 公分手臂彎曲赤手狀態內外展力矩為 4.6%BW*arm (18.33Nm)。

屈曲伸展力矩方面，4 公分手臂彎曲赤手狀態之屈曲伸展力矩為-8.44%BW*arm (-33.6Nm)，4 公分手臂彎曲赤手狀態約比手臂伸直赤手狀態減少 35%(-8.44 v.s.-5.41%BW*arm)，8 公分手臂彎曲赤手狀態之屈曲伸展力矩為-8.87%BW*arm (-35.3Nm)，8 公分手臂彎曲赤手狀態約比手臂伸直赤手狀態減少 50%(-8.87 v.s.-4.39%BW*arm) (表二)。

內外轉力矩方面，4 公分手臂彎曲赤手狀態內外轉力矩為 6.47%BW*arm (25.78Nm)，4 公分手臂彎曲赤手狀態約比 4 公分手臂伸直赤手狀態減少 67% (6.47v.s.2.10%BW*arm)，8 公分手臂彎曲赤手狀態內外轉力矩為 6.4%BW*arm (25.5Nm)，8 公分手臂彎曲赤手狀態約比手臂伸直赤手狀態減少 66%(6.4 v.s.2.12%BW*arm)。

表一　向前跌倒時 手臂伸直與彎曲時肘關節力

	4cm 手臂伸直	4cm 手臂彎曲	8cm 手臂伸直	8cm 手臂彎曲
肘關節力 A/P 剪力 (%BW)				
	12.91±6.22	-13.70±4.80$^{\#}$	18.52±9.12*	-13.03±4.48$^{*\#}$
肘關節力 M/L 剪力 (%BW)				
	-22.58±10.08	-27.31±8.29	-33.15±10.16*	-36.83±9.83*
肘關節力 Axial 壓力 (%BW)				
	80.35±9.90	54.03±4.16$^{\#}$	113.35±25.98*	90.64±22.96$^{*\#}$

*:與 4cm 跌落高度比較有明顯差異 $p<0.05$　#:與手肘彎曲比較有明顯差異$p<0.05$

表二　向前跌倒時 手臂伸直與彎曲時肘關節力矩

	4cm 手臂伸直	4cm 手臂彎曲	8cm 手臂伸直	8cm 手臂彎曲
肘關節力矩 Adduction / Abduction (%BW*Arm)				
	2.97±1.34	6.43±4.01	2.78±1.27	4.60±2.27
肘關節力矩 Flexion / Extension (%BW*Arm)				
	-5.41±3.43	-4.39±2.22	-8.44±2.16*	-8.87±2.07*
肘關節力矩 Pronation / Supination (%BW*Arm)				
	-2.10±1.33	-2.12±1.05	-6.47±4.65*	-6.40±3.46*

*:與 4cm 跌落高度比較有明顯差異 $p<0.05$　#:與手肘彎曲比較有明顯差異$p<0.05$

ADAMS LifeMOD 模擬

圖 6 與圖 7 分別為體重 70 公斤身高 175 公分的年輕人體位，進行 ADAMS LifeMOD 模擬向前跌倒之手臂伸直與手臂彎曲時情形，而由模擬軟體 ADAMS LifeMOD 所得到的地面反作用力與肘關節軸向力結果與實驗結果有接近的峰值但是模擬曲線陡峭與趨勢(圖 8)，。

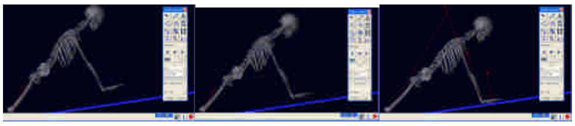


圖 6　向前跌倒時之手臂伸直模擬情形

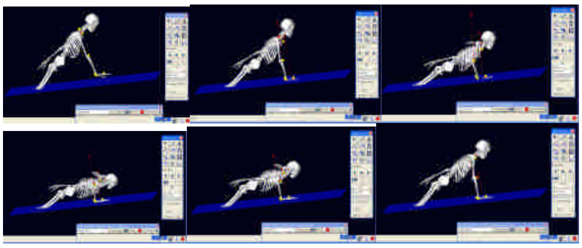


圖 7　向前跌倒時手臂彎曲之模擬情形

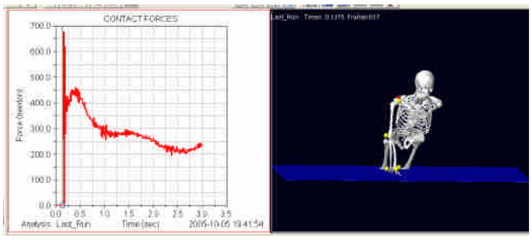


圖 8　手臂彎曲向前跌倒之地面反作用力

五、討論與結論

本研究以手伸直與手臂彎曲向前跌倒實驗資料，配合人模擬軟體 Adams+Lifemod，以地面反作用力以及肘關節作用力，作為比較對象。

地面反作用方面，本研究結果顯示，跌落高度愈高，第一峰值愈明顯增加，8 公分手臂伸直赤手狀態之第一峰值，約比 4 公分手臂伸直狀態之值增加 73%。跌落高度的變化對於地面反作用力的影響與 Chou[14]和 Chiu[18]中有相同的趨勢。第二峰值亦隨著跌落高度增加而增加，但增加幅度不如第一峰值明顯，8 公分赤手手臂伸直狀態之第二峰值，約比 4 公分手臂伸直狀態之值增加 8%，此結果亦與 Chiu[18]中有相同的趨勢。另外，兩峰值產生時間亦隨著跌落高度增加而減少。

跌倒策略方面，本研究結果顯示，8 公分赤手手臂彎曲狀態下之地面反作用力，約比手臂伸直狀態之值減少 37%，在策略的變化結果中與 Chou[14]有相同趨勢，跌落時手臂自然彎曲能減少第一峰值，並且能延遲第一峰值發生時間，4 公分手臂彎曲赤手狀態第一峰值產生時間約比手臂伸直狀態增加 22%，但隨著

跌落高度增加，第一峰值所延遲時間能力驟減，8 公分手臂彎曲赤手狀態第一峰值產生時間約比手臂伸直赤手狀態僅增加 2%。主要原因由於第一峰值是由速度瞬間為零所造成，因此與跌落高度與速度有絕對關係，而第二峰值是由受測者抵抗身體位能所造成，因此與體重與受測者本身承受身體位能所對應策略有關，由手臂彎曲狀態下之第二峰值產生時間變異較大，得知雖然限制每位受測者採用手臂彎曲策略，但仍然由於每位受測者肌肉反應或心理負荷不同，造成較大變異。

模擬方面，模擬手伸直結果與實驗結果在地面反作用力上有一致的趨勢，但是在反應時間上比實驗的資料早，結果與 Chiu 的 two-mass 的模型有相似的趨勢，也類似之前研究報告；模擬手彎曲結果與實驗結果在地面反作用力上也有一致的趨勢，第一峰值稍為大，而第二峰值較小，曲線結果也較早發生與峰值斜率較實驗值大，這可能與人體在完成手臂彎曲時，身體上肢肌肉骨骼作用力到大小與時間關係差別有關，由於人體由釋放架啟動到碰撞地面時間相當短，人體在這麼短的時間要完成手彎曲並不容易，因此有各許多的情形，也影響摩擬結果。但是透過人體動作實驗的資料與人體動作模擬軟體的使用，可以用來預測人體關節受力，提供臨床跌倒傷害評估及預防之參考。

七、計畫成果自評

本研究以完成手伸直與手彎曲人體動作實驗，並計算得到地面反作用力、腕關節、肘關節的關節作用力與力矩，並且透過人體動作模擬軟體的使用，由人體動作實驗中反光球資料作為輸入值，計算人體關節受力，再以修正關節特性方式，求得較接近的模擬模型。

人體動作模擬模型可以用來預測人體關節受力，對於高度太高的跌倒或危險性較高的動作，人體關節受力傷害的預測，有很重要的參考作用。但是由於肌肉、韌帶與關節特性對模擬的誤差影響很大，因此必須仰賴更多的肌肉骨骼基本參數的量測數據，方能有較佳的模擬結果。

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出席國際學術會議心得報告

計畫編號	94-2614-E-040-003-
計畫名稱	向前跌倒策略對上肢關節影響的生物力學分析與模擬
出國人員姓名 服務機關及職稱	羅世忠 中山醫學大學 職能治療學系 助理教授
會議時間地點	荷蘭馬司垂克(Maastricht, Netherlands)
會議名稱	Proceedings IEA 16th World Congress on Ergonomics, July 10-14,
發表論文題目	Effects of wrist guard and arrest strategies on impact force.

一、參加會議經過

此次第十六屆國際人因工程研討會日期為7月10日至7月14日在充滿人文素養的荷蘭馬司垂克舉行，由於這次隨行得有許多人因工程前輩先進，讓此次研討會的收穫更加豐富。此研討會為三年舉辦一次之國際人因工程研討會，會議的主題為「人因工程之多樣性」，會場在馬斯垂克會展中心舉行 (Maastricht Exhibition and Congress Center, MECC)，其研討議題包括人體計測(Anthropometry)、老年人因(Aging)、應用人因設計(Applied ergonomics in design)、航空與人因(Aviation & ergonomics)、生物力學模式(Biomechanical Modeling)、認知人因(Cognitive Ergonomics)、生產系統製造與管理人因之整合(Design and management of production systems: integration of human factors and ergonomics)、環境(Environment)、人機介面 (HCI)、人員績效與可靠度(Human Performance and Reliability)、人工物料搬運(Manual Materials Handling)、組織設計與管理(Organizational design and management, ODAM)、參與性人因(Participatory Ergonomics)、各種座談會(Symposium)與海報(Posters)等研討議題。
會場中還有許多富有人因設計的概念產品展示，是一個人因工程學者、廠商與研究成果相互交流的大聚會。

第一天（7/10）為開幕式及專題演講，下午有分組報告。
第二天（7/11）除分組報告外，包括座談會。
第三天（7/12）上午為座談會與分組報告， 下午參訪馬斯垂克市中心。
第四天（7/13）上午為分組報告，我的報告場次排在上午10點的生物力學研討室
第五天（7/14）上午為分組報告，下午散會。

二、 與會心得

這次與會除了與國內許多先進學者有較多交流的時間，聚集許多想法與未來可能的合作計畫，也聽取國際學者在各個人因工程與生物力學上的經驗與成果，增加研究深度與廣度，而這些想法或衝擊都必須在這種國際交流下，才有可能創造出來。

另外，在荷蘭的期間，見識到異國文化帶來的新的想法，比如騎乘腳踏車在荷蘭幾乎是生活的一部分，腳踏車道也四通八達，對比摩托車成群的台灣，應有許多新的思維。對於國際的追求，雖然荷蘭使用荷蘭語與但是英文也相當流利，也很樂意用英語交談。

感謝國科會的經費支助，讓這次的研討會順利成行，也讓我相當充實。

Effects of wrist guard and arrest strategies on impact force

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Abstract

Wrist guards are one of the protective devices widely used for preventing from a distal radius fracture during in-line skating and snowboard-related activities. However, more than half of the people wearing wrist guards sustained a fracture of the wrist on forward falls. The purpose of this study was to evaluate the three factors, materials of wrist guard, fall heights and arrest strategies, on impact force during forward fall by biomechanical experiments,

Ten physically healthy male subjects volunteered for this investigation. None had ever suffered from upper extremity injuries or disorders. The Vicon Motion System (Vicon 460, Oxford, UK) with six 120 Hz cameras and one 1000Hz AMTI force-plate (type BP600900-6-1000, AMTI) was used to measure relative joint positions and ground reaction force (GRF) from a self-established releasing system. Joint force, GRF and impact time were then analyzed for effects of three parameters on impact force during forward falls. The first parameter was materials of wrist guard including bare hand (BH), common wrist guard (WG), wrist guard with pad on the palm (WG+) and WG+ removing splint below (WG-). The second parameter was arrest strategies including elbow extended and flexed. The third parameter was fall height including 4cm and 8 cm above force plate.

The results of this study were as follows. The impact force, loading rate, and all axial joint force of elbow significantly increased as the increase of fall height. The strategy of elbow flexed could attenuate the GRF peak force and delay the time of peak impact force. In the effect of materials, the GRF, loading rate and compressive joint force with WG+ and WG- decreased significantly than those with BH and WG. The conclusion is that lower falling height, using wrist guard with a compliant pad (WG+ or WG-) and the strategy of elbow flexed will provide the comfortable impact and decrease the risk of upper extremity.

Keywords: wrist guard, forward falls, ground reaction force, arrest strategy

1. Introduction

Falls on the outstretched hand are the cause of approximately 90% of fractures at the distal radius, humeral neck, and supracondylar region of the elbow [1, 2]. Wrist guards are one of the protective devices widely used for preventing from a distal radius fracture during in-line skating and snowboard-related activities [3]. However, more than half of the people wearing wrist guards sustained a fracture of the wrist on forward falls [4].

Earlier wrist guard related studies failed to obtain the real fall data [5]. The purpose of this study aimed to fill the gap by biomechanical experiments to evaluate the effects of materials of wrist guard, fall heights and arrest strategies, on impact force during forward fall.

2. Methods

2.1 Subject and Experimental Protocol

Ten physically healthy male subjects volunteered for this investigation. They ranged from 23 to 28 years (26±2.6, mean±SD) of age, from 58 to 81 kg (72.8±10.2, mean±SD) in body weight, and from 161 to 184 cm (172.6±6.1, mean±SD) in body height. None had ever suffered from upper extremity injuries or disorders. The Vicon Motion System (Vicon 460, Oxford, UK) with six 120 Hz cameras and one 1080Hz AMTI force-plate (type BP600900-6-1000, AMTI) was used to measure relative joint positions and ground reaction force (GRF) from a self-established releasing system.

A set of nine reflective markers was placed on selected anatomic landmarks on the subject putting on a wrist guard. During the experiment, the subjects initially assumed a one-handed push-up, the elbow full extended, the arm oriented 15° from the vertical, and the leg at 30° from the horizontal. The fall height was set by pulling the subject with releasing system (see Fig. 1). Three parameter was controlled by randomly select during experiment. The first parameter was materials of wrist guard including bare hand (BH), common wrist guard (WG), wrist guard with pad on the palm (WG+) and WG+ removing splint below (WG-). The second parameter was arrest strategies including elbow extension and flexion. The third parameter was fall height including 4cm and 8 cm above force plate. Each subjects provided informed consent.

2.2 Data Reduction

Laboratory-developed kinematics and kinetics software were used to calculate the joint resultant forces of the elbow. Six CCD cameras were used to record 3-D position of the markers. A force plate was used to measure vertical and two shear forces as well as the location of the center of pressure on the palm and the moment about the axis normal to the force plate during the fall. Simultaneous measurement of the upper-extremity kinematics was obtained by video recording of the markers. The elbow joint loading is then calculated, using an inverse dynamic procedure with the Newton-Euler equations. A generalized cross-validation spline smoothing (GCVSPL) routine at a cutoff frequency of 6 Hz was used for data smoothing.

GRF, impact time and Joint motion and force were then analyzed for effects of parameters on impact force during forward falls.

2.3 Data Analysis

The data, ground reaction force, impact time and elbow joint force, among materials of wrist guard, arrest strategies and fall height was analyzed statistically by repeated three-way ANOVA with $p<0.05$ as statistical significance.

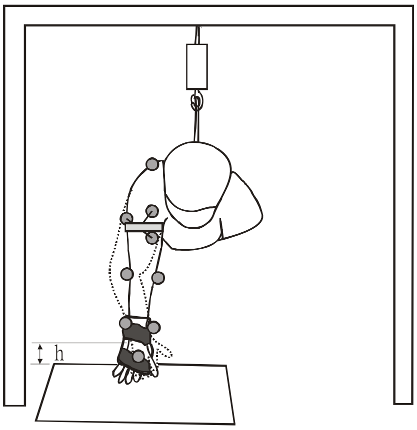

Fig 1: Experimental setup on a forward fall with wrist guard

3. Results

3.1 Ground reaction force

For all subjects, hand contact forces during 4 and 8 cm falls were characterized by a high frequency peak and a lower frequency peak. First peak ground reaction force on WG+ and WG- group was significantly different than that on BH group ($p<0.05$, see Fig. 1). First peak ground reaction forces were significantly affected by arrest strategies and fall height ($p<0.05$, see Fig. 1). Increases in fall height caused statistically significant increases in first peak value. The action of elbow flexion used caused decreases significantly the first peak value of ground reaction force.

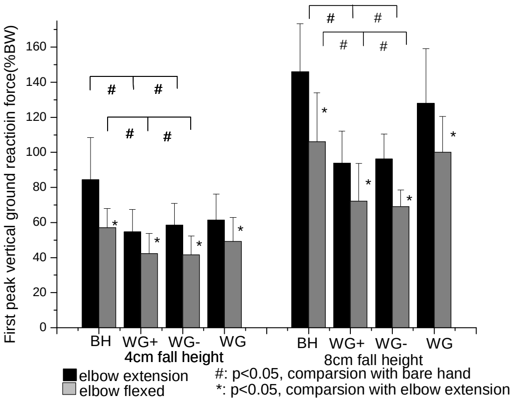

Fig 2: Mean and standard deviation of first peak value of ground reaction force while performing forward fall

3.2 First peak time

First peak time was defined by the period of the onset of impact to the time of first peak force. First peak time on WG+ and WG- group was significantly different than that on BH group (p<0.05, see Fig. 3). First peak times were significantly affected by arrest strategies on WG+ and WG- group (p<0.05, see Fig. 3).

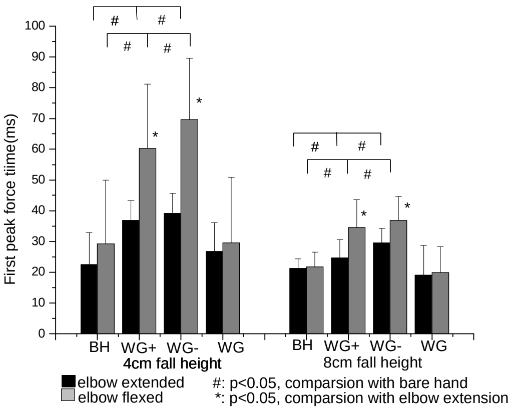

Fig 3: Mean and standard deviation of first peak force time while performing forward fall

3.3 Eelbow joint force

In the effect of materials, the compressive joint force with WG+ and WG- decreased significantly than those with BH and WG (p<0.05, see Fig. 4). The compressive axial force of elbow in elbow flexion significantly increased than that in elbow extension. (p<0.05, see Fig. 4).

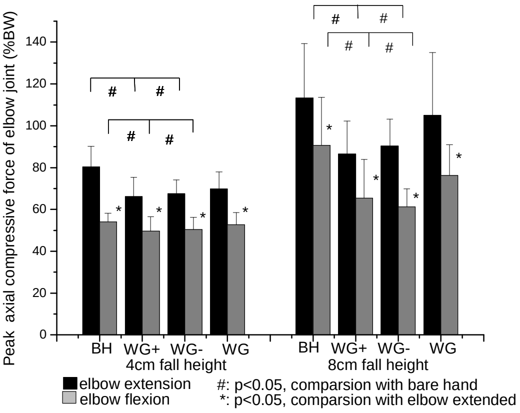

Fig 4: Mean and standard deviation of axial compressive force of elbow joint while performing forward fall

4. Discussions and conclusions

With the increase of the clinical importance of forward falls, several studies conducted have investigated the relationship between impact force and fall height during falls. In Chiu's study, the force applied to the wrist during a forward fall on the outstretched hand is dominated by a high-frequency transient occurring shortly after impact, followed by a low-frequency oscillation. In Chou's study, the action of elbow flexion could decrease the peak impact force, maximal axial force of elbow and delay the time of peak [1]. The present study showed the same trend. In addition, the impact time increased significantly on the help of wrist guard with pad (WG+, WG-).

Compared with the wrist guard related researches, Giacobetti found that wrist guard did not provide effective in preventing wrist fracture [5]. In Staebler's study found that volar plate design may affect load transfer to nearby anatomic structures [3]. Hwang noted that common wrist guard design should provide more compliant padding in the volar side for improved impact force attenuation through optimal selection of the material and biomechanical design for better protective functions [6]. In this study, the wrist guard did not provide effective decrease on impact force except adding pad on the volar (WG+ and WG-), especially when the fall high increased. Even though the WG group was found that a volar splint in common wrist guards plays a role of limiting the wrist extension in conjunction with a dorsal splint, the effective prevention of injuries during falling, in this study, was not statistic significance. With the pad inside, the impact force decreased significantly.

We conclude that lower falling height, using wrist guard with a compliant pad (WG+ or WG-) and the strategy of elbow flexed will provide the comfortable impact and decrease the risk of upper extremity

Acknowledgements

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