SYMPOSIUM PRESENTATION 3: PHYSICAL AND MENTAL HEALTH

Current understandings and technologies for prevention of fall-related hip fracture in older adults
W. J. Choi (Convener)

Participants*:* W. J. Choi (Korea), Y. Yang (Hong Kong), K. Lim (Korea), C. Y. Ho (Hong Kong). **ISSUE** Consequences of falls in older adults (i.e., hip fracture) are often life-threatening, and prevention is important. While tremendous efforts have been made so far to address fall-related hip fractures in older adults, fall-related death rates in older adults have continuously increased over the decades, requiring continued supports for research, development and application in safe activities of daily living. **CONTENT** Our symposium is designed to provide basic knowledge on the science of falling and hip fracture in older adults and associated intervention strategies (i.e., primarily wearable hip protectors), with a hope to guide future research and practice to address the issue. The symposium discusses hip fracture mechanisms and associated risk factors with a great emphasis on the circumstances of falls that lead to hip fracture and the role of soft tissue over the hip region, so called “natural padding device”, in determining hip fractures during a fall. The symposium also discusses wearable hip protectors, including its user compliance (acceptance and adherence) and novel design of hip protectors. **STRUCTURE** Choi first provides an overview on the science under fall-related hip fractures in older adults. Next, Yang talks about circumstances of falls that lead to hip fractures in older adults. After that, Lim talks about the role of trochanteric soft tissue (what/why is important) in context of hip fracture risk in the event of a fall. Finally, Ho provides some results on the user compliance of hip protectors in Hong Kong area and a newly designed hip protector that may help to improve protection and compliance. **CONCLUSION** A potential reason why the fall-related injuries in older adults have not been sufficiently addressed so far, may be due, in part, to ineffective interventions developed up on incomplete understanding of the injury mechanisms and circumstances. Continued efforts and concerns are warranted to solve the growing problem in a fast ageing society.

Keywords: falls, hip fractures, injury prevention, older adults, biomechanics, hip protectors, compliance, acceptance
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Science of falling and injury in older adults – Do all falls lead to death?: Literature Review

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Purpose Hip fractures are life-threatening injuries in older adults, and more than 95% of cases are due to a fall. Since consequences of hip fractures are debilitating, prevention is important. Development of effective prevention strategies requires sound knowledge on the injury mechanisms during a fall, and research studies to date provide several pieces of information (i.e., risk factors, injury mechanisms) to suggest prevention strategies (i.e., exercise programs, hip protectors, safe landing strategies, and so on). However, the problem doesn't seem to be solved yet, and fall-death rates in older adults has continuously increased over the past decades, anticipating seven fall deaths every hour by 2030 (CDC, 2017; Burns and Kakara, 2018). This indicates that current intervention strategies are ineffective in fast growing aged population. **Method** We reviewed literatures to summarize current biomechanical understandings and prevention strategies of falls and hip fractures in older adults to help guide a future direction on research and application. **Results and Discussion** (1) While falls are a number one cause of hip fracture in older adults, not all falls result in hip fracture, leaving more than 98% of falls non-injurious (Tinetti et al., 1988; Sattin, 1992). This forces us to think of factors that differentiate injurious versus non-injurious falls, and circumstances that lead to hip fractures. (2) Research evidence suggests that the injurious falls are determined with various biomechanical factors, including but not limited to, falling velocity, body mass, soft tissue stiffness, muscle pulling force, knee position at the time of hip impact, hip impact angle, fall direction, body mass index, age, femur geometry, and bone density. While effects of each individual factor have well been documented, combining effects and correlation and causation among the risk factors are poorly understood. (3) The fall-related hip fractures in older adults may be addressed by reducing individuals' fall risk during activities of daily living, or decreasing fracture risk in the event of a fall, and the fall prevention interventions include exercise, vision correction, vitamin D intake and environment modification. Whereas, the fracture prevention strategies include use of hip protectors, compliant flooring, and safe landing strategies, vitamin D intake and exercise (Choi et al., 2021). (4) While fall risk assessments have well been established and widely used in clinics and research, injury (fracture) risk assessments are relatively under-developed. (5) Development of fracture risk assessment techniques or tools along with better understanding on the correlation and causation among risk factors of falls and hip fractures in older adults, are necessary to establish more effective intervention models for fall-related hip fractures in older adults.

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Associations between fall characteristics and the occurrence of hip fracture among older adults in long-term care

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Purpose Falls are the cause of over 95% of hip fractures in older adults (Parkkari et al., 1999). An improved understanding of the circumstances of falls that lead to hip fracture may guide the development of strategies for hip fracture prevention (Yang et al., 2020). In this study, we video-captured and analysed real-life falls in two long-term care facilities to determine the biomechanical parameters that may contribute to the occurrence of hip fracture. **Method** Between April 2007 and October 2018, we captured 2377 falls by 646 residents, in which 30 falls resulted in hip fracture. The mean age (SD) of participants was 82.6 (9.1) years and 57% were female. Each video was analysed by a 3-member team using a validated questionnaire (Yang et al., 2013) to determine the height of the fall, activity at time of fall, occurrence of pelvis impact, initial fall direction, landing configuration, and attempts to recover balance by stepping. For the purpose of this study, we developed an additional questionnaire to determine the sequence of impact to body sites during falls, the orientation and location of pelvis at impact. Generalized Estimating Equations (GEEs) were used to determine relative risk ratios (RRs) for hip fracture associated with various fall characteristics. **Results and Discussion** Rate of hip fracture was 1.3% (30/2377). All 30 hip fractures involved falls from standing height and pelvis impact with the ground. 28 (93%) falls occurred during walking or standing, and 2 (7%) during rising. Regarding the pelvis orientation at impact, 23 (77%) falls were at the posterior-lateral, 4 (13%) at lateral, and 3 (10%) at posterior or anterior aspect of pelvis. After excluding falls from lower than standing height, risk for hip fracture was higher for sideways landing configurations (RR = 5.50; 95% CI 2.36-12.78) than forward or backward, and for falls causing hip impact (3.38; 1.49-7.67) (Figure 1). However, hip fracture risk was just as high in falls initially directed sideways as forward (1.14; 0.49-2.67), due to the tendency for rotation during descent. Falling while using a mobility aid was associated with lower fracture risk (0.30; 0.09-1.00). Hip protectors were worn in 73% of falls, and hip fracture risk was lower in falls where hip protectors were worn (0.45; 0.21-0.99). Age and sex were not associated with hip fracture risk. There was no evidence of spontaneous fractures. Based on observation of real-life falls, our study provided the first evidence on how fall characteristics are associated with the risk of hip fracture. Compared to non-fracture falls, all hip fractures were resulted from falls from standing height. Pelvis impact occurred generally as the first three sequential sites, which may lead to high energy causing hip fracture. The direct contact of the posterior-lateral pelvis to the ground may also increase the severity of impact at the greater trochanter region. Results from our study will contribute to the design of wearable hip protectors and exercise-based strategies to reduce risk for hip fracture in older adults.

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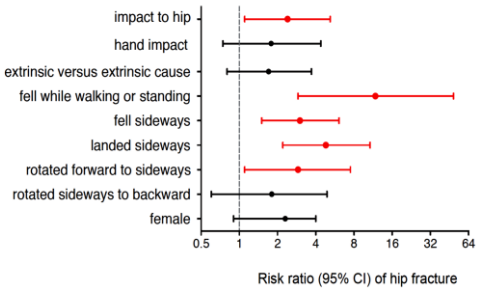

Figure 1. Relative risk ratio and 95% CI of the fall characteristics on the risk of hip fracture.

Keywords: falls, older adults, long-term care, hip fracture, biomechanics of falls, risk factors
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Biomechanics of the trochanteric soft tissue during a fall and hip fracture in older adults

K. Lim, W. J. Choi

Purpose Hip fractures are a major cause of elderly's mortality (Grisso et al., 1990), and insufficient understanding of fall-related hip fracture mechanism results in anticipation that fall deaths increases up to forty-three thousand by 2030 (Burns and Kakara, 2018). Several biomechanical factors have been identified to affect the risk of hip fracture during a fall, but lack of research exists on how the soft tissue covering over the hip area plays in determining hip fracture and whether it is a biomarker of hip fracture. **Method** Four research studies have been conducted to address this issue. Three have been published as journal articles and one is in preparation for submission to a journal. This symposium summarizes findings of the research studies. **Results and Discussion** The first study, titled "Soft tissue stiffness over the hip increases with age and its implication in hip fracture risk in older adults" (Lim and Choi, 2019), examined how protective benefits of soft tissue covering over the hip region change with age, and found that the soft tissue stiffness is 26% greater in older than young adults and increases with 1.33N/m every year. The second study, titled "Effect of fall characteristics on the severity of hip impact during a fall on the ground from standing height" (Lim and Choi, 2020), investigated how hip impact force during a fall was affected by mechanics of a fall (i.e., fall direction, knee boundary condition), and found that the actual hip impact force averages 4 kN, which is largely affected by fall mechanics and decreases up to 59%, depending on how they land on the ground. The third study, titled "The effect of the hip impact configuration on the energy absorption provided by the femoral soft tissue during sideways falls" (Lim and Choi, 2021), quantified the amount of energy absorbed by the trochanteric soft tissue during a fall, and how the energy absorption was affected by hip impact configuration. The study found that the energy absorption provided by the femoral soft tissue ranges from 0.03 to 3.05 joule during a fall, and protective benefits are smallest with anteriolateral hip impact, compared to lateral or posteriorlateral hip impact. The last study, titled "Correlation between trochanteric soft tissue stiffness and hip fracture risk during sideways falls" examined whether hip fracture risk was predicted with trochanteric soft tissue stiffness. The study found that there exists a linear relationship between the trochanteric soft tissue stiffness and body stiffness during sideways falls. The study also found that the soft tissue stiffness measured by a commercially available clinical device is ineffective in predicting the body stiffness. **Conclusion** The research provides insights on how the trochanteric soft tissue plays in determining hip fracture risk and whether it is a biomarker of hip fracture, which should help improve intervention strategies for hip fracture prevention in older adults.

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Keywords: biomechanics, fall, hip fracture, older adults, soft tissue stiffness

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Promoting user compliance with wearable hip protectors in older adults through education and technology

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Purpose Falls cause up to 95% of geriatric hip fractures, of which the rates are two- to three-fold higher in care facilities. Hip protectors (HP) have been proven effective against fall-related hip fractures (Korall et al., 2019); however, user compliance with HPs in care facilities remains very low, particularly in Hong Kong (<20%). Recent studies show that user compliance can be facilitated through structured education for caregivers and better design of HP that enhances comfort of wearing (Korall et al., 2015). Therefore, our study sought to promote user compliance with wearable HP among older adults in care facilities in Hong Kong through structured training for caregivers and innovative designs of 3D-printed HP. **Method** Ninety-four care workers from five care facilities attended a 60-minute educational session on the epidemiology of hip fractures and related consequences, strategies to prevent falls and hip fractures, and effectiveness and approaches for successful implementation of HP. After the education sessions, we recruited 69 residents from the care facilities and provided free hip protectors to them. Resident compliance with wearing hip protectors was recorded on a weekly basis, and the sustained adherence was evaluated after six months. Qualitative feedback on the use of hip protectors from residents and their care givers was collected via phone interviews and incident reports. Meanwhile, based on participants' feedback and previous research evidence, we developed a customized, comfortable and breathable HP through 3D-printing technology. Specifically, selective laser sintering technology was applied to fabricate TPU (Thermoplastic Polyurethane) such that HP could be designed based on the users' hip profile. More importantly, we used our newly invented implicit design method, a conformal TPMS (triply periodic minimal surface) structure-infill generation scheme (Ding et al., 2021), to mass-customize hip protectors, with lattice structures to be automatically generated from the 3D scan data for multiple participants with individually tailored design (Figure 1). The biomechanical performance of the prototype of HP was then tested through an impact on the force plate using a drop tower. **Results and Discussion** Our preliminary data showed a satisfactory adherence rate [46.4% (32/69)]. For residents who failed to adhere to wearing HP, more than half of them [54.1% (20/37)] stopped using within first two weeks. Common reasons for not using HP include discomfort [62.2% (23/37)] (e.g., protectors are not breathable, too tight, or causing skin irritation), inconvenience [37.8% (23/37)] (e.g., don off garment during toileting), and perceived ineffectiveness [8.1% (3/37)]. The feedback coincided with barriers in promoting HP user compliance identified from previous research (Korall et al., 2015). Clearly, perceived ineffectiveness can be further enhanced by providing education to users. Meanwhile, our novel 3D-printed HP was lighter, more breathable, and better fit than conventional HPs. It would be more suitable for users in Hong Kong, where summer days are hot and humid. Pilot biomechanical tests showed higher force attenuation in our 3D-printed HP than the conventional models. Further investigation on user compliance with the novel 3D-printed HP will be carried out.

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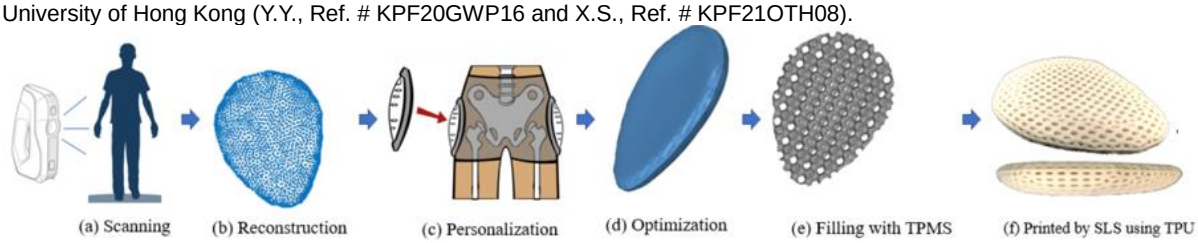

Figure 1. Flowchart of the Auto-design Model generation process: (a-b) 3D-scan to obtain the hip profile of the user as point cloud; (c) input the user's BMI and other personalized parameters (e.g., sex, height, weight) for customization (d) optimize the point cloud reconstruction to create surface contour using Hermite Radial Basis Function (HRBF); (e) infill Triply Periodic Minimal Surface (TPMS) sheet structure lattice to create the hip protector model; (f) print the model using selective laser sintering (SLS) of thermoplastic urethane (TPU) to produce the customized hip protector.