中文摘要

流行性感冒是一高傳染性之室內氣懸感染性疾病，可造成全球每年嚴重之發病率與死亡率。潛在之人與人傳輸為流感流行之主要因素，高感染風險可能與人體呼吸道感染有關。本研究目的為針對室內呼出/吸入之流感飛沫發展一架構，評估族群傳輸動態、感染風險及可控制比例。本研究以人體呼吸道實驗數據重新建構流感飛沫粒徑分佈。以易感–感染–復原–環境區塊模式模擬族群傳輸動態與推估基本再生數(R_0)，同時亦建構流感飛沫吸入模式與人體呼吸道模式評估在呼吸道中流感飛沫之吸入與沉積。以劑量反應模式結合機率風險評估方法分析流感感染風險。為擬定室內環境中流感之最佳化控制策略，本研究以 R_0、無症狀感染比例(θ)及控制策略效能(ε_k)為主建立一控制模式，同時亦檢視使用抗病毒藥物後對於降低流感感染風險之治療效能。此外，以韋伯累積閾值模式估計在輕度症狀下流感患者體內病毒力價之閾值(γ)。研究結果指出，針對咳嗽與打噴嚏所產生流感飛沫之平均粒徑分別為 0.34 與 7.68 μm。飛沫核(0.3 – 1 μm)、小飛沫(1 – 10 μm)及大飛沫(10 – 100 μm)之 R_0 推估值分別為 1.68 (95%信賴區間：0.34 – 6.31)、2.29 (0.66 – 7.48)及 4.17 (1.17 – 14.86)。此外，在平衡狀態下人體吸入飛沫核、小飛沫及大飛沫之流感飛沫濃度，分別為 1.01×10^4 (4.35×10^3 – 2.37×10^4)、1.83×10^4 (7.97×10^3 – 4.14×10^4)及 447 (199 – 988) pathogen ml^{-1}。本研究顯示室內流感飛沫更可造成上呼吸道之感染風險。本研究亦指出適當之控制策略與抗病毒藥物可有效控制室內流感飛沫，且在輕度症狀下流感患者不會造成室內流感流行。本研究以動態模擬觀點提供一新穎之風險評估與控制架構，可適切地評估室內流感感染風險。

關鍵字：流行性感冒；室內飛沫；動態模擬；病毒釋放；機率風險；控制策略

Abstract

Influenza is a highly contagious indoor airborne infectious disease, leading to severe morbidity and mortality worldwide annually. The potential human to human transmission is primarily contributed to the influenza epidemic. The high infection risk may associate with the infection on human respiratory tract. The objective of this study was to develop a framework for assessing population transmission dynamics, infection risk, and controllable ratio for indoor exhaled/inhaled influenza droplets. This study used human respiratory droplet experimental data to reconstruct the influenza droplet size distribution. The compartmental susceptible-infected-recovery-environment model was used to simulate the dynamics of population transmission and to estimate basic reproduction number (R_0). This study also established the influenza droplet inhalation and human respiratory tract models to assess inhalation and deposition of influenza droplets. A dose-response model linked with a probabilistic risk assessment approach was used to analyze influenza infection risk. To define an optimal control strategy for influenza in indoor environments, this study constructed a control model in terms of R_0, asymptomatic infectious proportion (θ) and control measure efficacy (ε_k). This study also examined the treatment efficacy after using antivirus drug on reducing influenza infection risk. The Weibull threshold model was used to estimate the viral titer threshold (γ) at mild symptom. The results indicated that the mean diameters of influenza droplet were 0.34 and 7.68 μm for coughing and sneezing, respectively. R_0 values were 1.68 (95% CI: 0.34 – 6.31), 2.29 (0.66 – 7.48), and 4.17 (1.17 – 14.86) for droplet nuclei(0.3 – 1 μm), small droplet(1 – 10 μm), and large droplet(10 – 100 μm), respectively. The equilibrium inhaled influenza droplet concentrations were 1.01×10^4 (4.35×10^3 – 2.37×10^4), 1.83×10^4 (7.97×10^3 – 4.14×10^4), and 447 (199 – 988) pathogen ml^{-1} for droplet nuclei, small

droplet, and large droplet, respectively. This study showed that indoor influenza droplets are more likely to pose infection risk in upper respiratory tract. This study also implicates that a proper control measures and antiviral drug could effectively control indoor influenza droplets. The threshold simulation indicated that indoor influenza epidemics were not outbreak for the infected individual with mild symptom. This study provides a novel risk assessment and control framework to better assess indoor influenza infection risk from a dynamic modeling point of view.

Keywords: Influenza; Indoor droplets; Dynamic modeling; Virus shedding; Probabilistic risk; Control measure