

Simple Strategy to Prevent Severe Head Trauma in Judo —Biomechanical Analysis—

Haruo MURAYAMA,^{1,2} Masahito HITOSUGI,³ Yasuki MOTOZAWA,³
Masahiro OGINO,⁴ and Katsuhiko KOYAMA²

*Departments of ¹Sports Science, ³Legal Medicine, and ⁴Neurosurgery,
Dokkyo Medical University School of Medicine, Shimotsuga, Tochigi;
²Department of Health Sciences, Interdisciplinary Graduate School of Medicine and
Engineering, University of Yamanashi, Kofu, Yamanashi*

Abstract

To determine whether the use of an under-mat has an effect on impact forces to the head in Judo, a Judo expert threw an anthropomorphic test device using the Osoto-gari and Ouchi-gari techniques onto a *tatami* (judo mat) with and without an under-mat. Head acceleration was measured and the head injury criterion (HIC) values with or without under-mat were compared. The use of an under-mat significantly decreased ($p = 0.021$) the HIC values from 1174.7 ± 246.7 (without under-mat) to 539.3 ± 43.5 in Ouchi-gari and from 330.0 ± 78.3 (without under-mat) to 156.1 ± 30.4 in Osoto-gari. The use of an under-mat simply reduces impact forces to the head in Judo. Rule changes are not necessary and the enjoyment and health benefits of Judo are maintained.

Key words: head injury, judo, prevention, head injury criteria, biomechanics

Introduction

Judo is one of the popular sports originated from Japan. As judo is performed in Olympic Games, this is widely performed in school or public facilities for education, training, or recreation. The growing popularity of judo has been focusing attention on injuries that may occur during judo practice in addition to benefits. Especially, cerebral concussions have often occurred in judo athletes. Pieter estimated the rate of cerebral concussions in young judo athletes as 2.38/1000 male athlete exposure and 2.92/1000 female athlete exposure.¹⁾ Furthermore, unfortunately, severe head injuries have often occurred in judo. Neurosurgeons in Japan reported 122 moderate to severe head injuries due to sports managed in an university hospital.³⁾ They suggested that 20 patients were injured by judo and of them, four patients suffered from acute subdural hematoma. Nishimura et al. reported other 4 cases of acute subdural hematoma due to judo practice, patients were all young males aged from 14 to 24.⁹⁾ Recently, in Japan, at least 30 severe head injuries have been reported from 2003 to 2010. Most of them (28 out of 30) suffered

from acute subdural hematoma.⁸⁾ Acute subdural hematoma associated with judo occurs primarily in adolescents and young adults due to the head contact to the *tatami* (judo mat). In throwing techniques of judo, a technique to minimize the contact of the head, neck, and other vital parts of the body to the *tatami*, called “Ukemi,” is learned and performed when fallen or thrown. However, as for the young beginner or inexperienced persons, this technique is not adequately performed, they sometimes attack their head and thereby suffer severe head injuries. Therefore, for preventing severe judo-related injuries especially for youth, interventions to scientific verifications are necessary.

The judo mat is either the *tatami* or similarly acceptable material approved by the International Judo Federation. In Japan, though most judo training halls are well equipped and the *tatami* is laid with shock absorber, there are some schools and public facilities where the *tatami* is simply laid on the floor. As there is no shock absorber, a player can experience large external impact forces when landing on the *tatami*. The characteristics of the *tatami* are well defined and regulated. However, there are currently no regulations regarding the need of a shock absorber.

The aim of this study was to determine whether the use of an under-mat can reduce the impact force to the head when landing on the tatami.

Materials and Methods

Judo throwing techniques

To ensure that a reliable and valid judo throwing technique was used, one Japanese male judo expert (26 yrs, stature 177 cm, mass 90 kg, black belt with 5th Dan) was recruited to repeatedly throw an anthropomorphic test device (ATD). Prior to the test, his informed consent was obtained. Moreover, this study protocol was approved by the Research Ethics Committee of the Dokkyo Medical University School of Medicine.

From a survey of judo injuries, conducted by the All Japan Judo Federation, most head injuries occur when being thrown by the Osoto-gari or Ouchi-gari techniques.⁸⁾ These two throwing techniques were therefore used in the present study. In Osoto-gari, the thrower (tori) breaks the recipient's (uke) balance toward his rear corner, causing the uke's weight to be largely on one leg and to the rear of the foot, by driving the outside leg forward to the side of the uke. Then,

the tori swings the other leg behind the uke at thigh level, and brings it back swiftly and strongly reaps the uke's leg, causing uke to be lifted off the tatami and to be fallen directly backward on to the tatami (Fig. 1). In Ouchi-gari, tori breaks uke's balance to the rear corner by pushing and bringing his body close to uke's. While balancing on one leg, the tori's free leg grazes the tatami in a large, circulator motion, going behind one of uke's legs and coming back to reap it. As the uke's weight and balancing are on his heels at the point of attack, he begins to fall backwards when tori reap uke's leg (Fig. 2).

An ATD is a mechanical model of the human body that is typically used in vehicle crash testing. Using ATDs, we can obtain mechanical loading parameters at impact which would be injurious for a living human. Among a number of state approved models, the POLAR dummy was used in the present study.^{1,4)} The POLAR (stature 175 cm, mass 75 kg) was designed to simulate the kinematics of the human body during car-pedestrian collisions and has high biofidelity. Higher similarity of this dummy to humans has been validated with some tests using post-mortem human subjects.⁴⁾ As the persons performing judo suffer from complex rotations or attacks of the

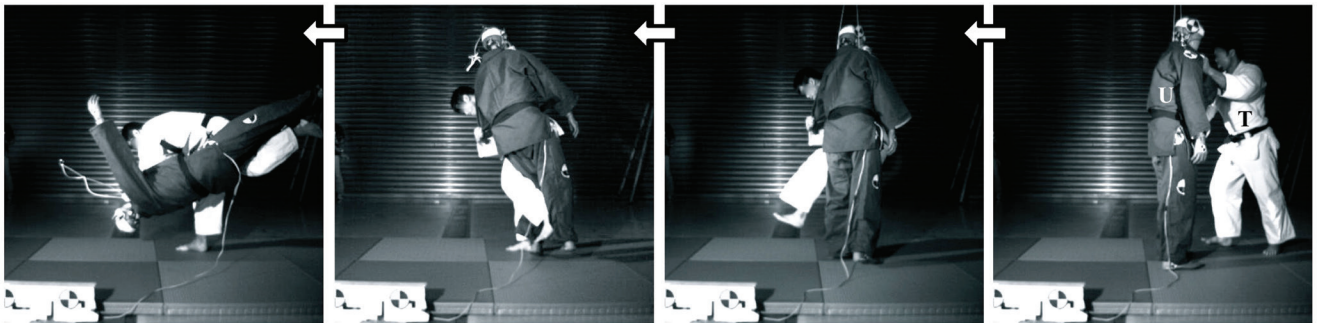


Fig. 1 Images of the Osoto-gari throw; white (T): the thrower (tori), black (U): the recipient (uke).

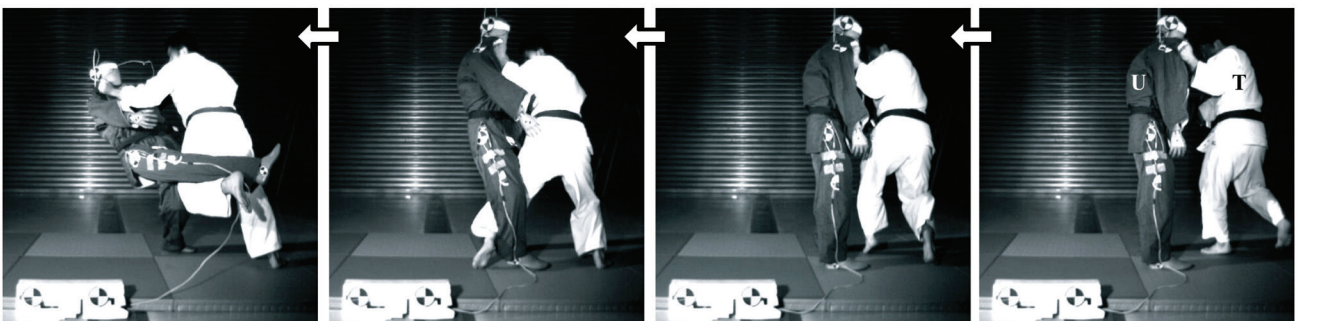


Fig. 2 Images of the Ouchi-gari throw; white (T): the thrower (tori), black (U): the recipient (uke).

body, POLAR is suitable for detecting the physical parameters with high reliability. A tri-axial accelerometer was mounted at the ATD head's centre of the gravity. The data were recorded using a high-speed data acquisition system, sampled at 20 kHz and filtered using a channel class 1000 filter. The ATD kinematics data were obtained using a high-speed digital video camera recording at 1000 frames per second.

Tatami and throw protocol

On the test day, the tatami (SV230, Hayakawa Textile Industries Co., LTD., Kashiwara, Osaka) was laid on a concrete floor. This type of tatami has been used at international judo tournaments. The expert then threw the ATD eight times using the Osoto-gari ($n = 4$) and Ouchi-gari ($n = 4$) techniques. Following these throws, a 60 mm thick synthetic sponge which consists of urethane and polyethylene mat (AM2202, Senoh Corporation, Matsudo, Chiba) was placed under the tatami. At the static load test, when the load of 200 N is applied to this mat, the depth of depression of the mat was between 10 mm and 20 mm. The throwing protocol was then repeated.

Analysis of biomechanical parameters

The head acceleration values were measured in each direction, Gx (longitudinal), Gy (lateral), Gz (vertical). The resultant acceleration (Gr) was then calculated as follows: $Gr = (Gx^2 + Gy^2 + Gz^2)^{1/2}$. The head injury criterion (HIC) was then calculated. The actual version of HIC was proposed by the US National Highway Traffic Safety Administration and is included in Federal Motor Vehicle Safety Standard, No. 208. HIC is still the most commonly used criterion for head injury in automotive or sports injury researches.¹⁵⁾ HIC is calculated using the following expression:

$$HIC = \left\{ (t_2 - t_1) \left[\frac{1}{t_1 - t_2} \int_{t_1}^{t_2} a(t) dt \right]_{\max}^{2.5} \right\}$$

In the equation, t_1 and t_2 are any two arbitrary time points during the acceleration pulse not to lay more than 15 ms, "a" is the acceleration due to gravity and time is measured in seconds. The resultant acceleration is used for the calculation.

Statistical analysis

The HIC values for the without under-mat versus with under-mat conditions were compared using a Mann-Whitney test. Differences with a p value < 0.05 were considered significant.

Results

ATD kinematics and acceleration

When the Ouchi-gari or Osoto-gari was performed, the dummy fell backwards with the occipital area of the skull contacting the tatami (Figs. 1, 2). Peak acceleration was observed at the initial contact. Because the force was applied from posterior to anterior, the largest acceleration was obtained in Gx (longitudinal direction). Based on the head acceleration diagrams for each test, peak acceleration was defined as the maximum value that was maintained for at least 3 ms.¹²⁾ Without an under-mat, peak Gx ranged from 51.6g to 79.9g (Osoto-gari) and 124.9g to 143.2g (Ouchi-gari). With the under-mat installed, the duration of the acceleration was prolonged and the peak values were decreased. Peak Gx ranged from 36.1g to 45.7g (Osoto-gari) and 73.7g to 92.4g (Ouchi-gari).

As Gx was the largest of the three acceleration directions, the resultant acceleration values were similar to that of Gx. Fig. 3 shows a representation of the time course of the resultant acceleration with and without under-mat in Osoto-gari and Ouchi-gari, respectively.

HIC comparison

The Osoto-gari and Ouchi-gari HIC values with and without under-mat were plotted and compared (Fig. 4). Without under-mat the HIC (mean \pm standard deviation) values were 330.0 ± 78.3 (Osoto-gari) and 1174.7 ± 246.7 (Ouchi-gari). However, with under-mat they were significantly ($p = 0.021$) decreased to 156.1 ± 30.4 (Osoto-gari) and 539.3 ± 43.5 (Ouchi-gari), respectively.

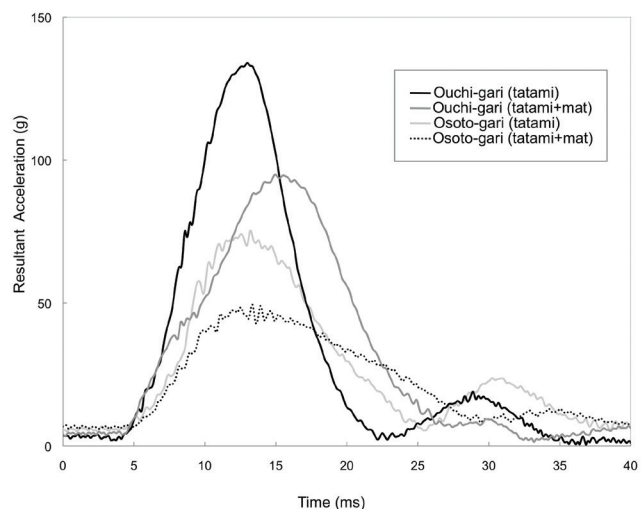


Fig. 3 Representative of the time course of the resultant acceleration with and without under-mat in Osoto-gari and Ouchi-gari, respectively.

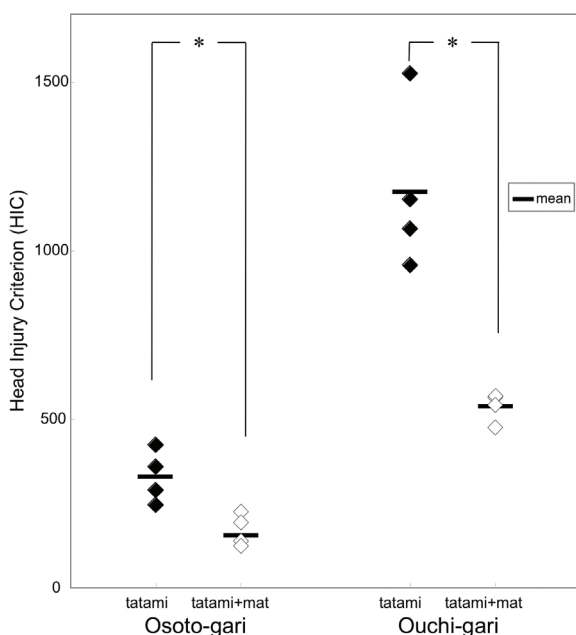


Fig. 4 Comparison of head injury criterion (HIC) score with and without under-mat in Osoto-gari and Ouchi-gari, respectively (*statistically significant, $p < 0.05$).

Discussion

Sports and recreation injuries account for 15–20% of injury presentations.¹³⁾ In sports injuries, head injury is quite popular. The US Centers for Disease Control and Prevention (CDC) estimates that approximately 300,000 sports-related concussions¹⁴⁾ and upwards of 3.8 million traumatic brain injuries occur in sports and recreational activities annually.⁶⁾

According to the British sports injury insurance registry data,⁵⁾ Judo had the second highest injury rate following karate, 117 injuries per 1000 person year of exposure. For children aged 16 years or less, the injury rate was 30, higher than soccer (25) or volleyball (12). Seventy percent of judo injuries occurred at training session, whereas 30% at competitions. Therefore, the specific injury preventive measures simply performed in daily judo training are needed. In judo, as the participants are subject to being fallen or thrown, severe head or neck injuries may occur. Direct impact to the head due to contact with tatami is considered as the predominant cause of head injury.

In general, the impact responses were described in terms of head acceleration according to the many cadaver and mechanical studies.¹²⁾ Therefore, these injury mechanisms are deeply related to kinetic

measures of translational acceleration.

Our study was designed to simulate the impact forces to the head in a situation where the uke is unable to protect his body using appropriate Ukemi. In this study, high values of acceleration were obtained in the longitudinal direction because the occipital area of the head struck against the tatami. This finding provides biomechanical data to support the findings that the impact forces to the head in judo can cause adolescents and young adults to experience acute subdural hematomas. The mechanism to explain this injury has been proposed to be a high impact force to the occipital area which results in brain movement, which leads to stretching and injury of the bridging veins.

This is the first study to provide HIC values of ATD in response to judo throwing techniques. The HIC is a good predictor of the probability of experiencing a severe head injury. An HIC value of 700 predicts the risk of a skull fracture at a 31.0% probability.²⁾ Research performed in the US National Football League reported that an HIC value of 250 is the threshold for concussion.¹⁰⁾ Based on the literature, the HIC values of 1174.7 ± 246.7 in Ouchi-gari and 330.0 ± 78.3 in Osoto-gari recorded without an under-mat would predict an increased risk of severe head injury.

To prevent severe head injuries an under-mat should be installed if judo training facilities are not equipped with a shock absorbing materials underneath the tatami. Head acceleration and HIC values were significantly decreased when an under-mat was placed beneath the tatami. It is proposed that the extra padding absorbs energy allowing for a longer deceleration time for the head, and consequently a reduced peak acceleration. The extent of energy absorption depends strongly on the characteristics of the under-mat, in particular its thickness and the shape. Future research would examine the effects of different modifications of the under-mat on HIC values in response to judo throwing techniques.

The values of HIC were higher in Ouchi-gari than in Osoto-gari. In Ouchi-gari, tori gets close to uke and strongly pushes him so that the impetus of the movement continues to drive uke backward. As uke's body is intensively fallen backward, the gained head linear momentum might cause higher HIC score in Ouchi-gari. Since the value of HIC is determined by translational acceleration without rotational factor, we cannot compare the actual risks of these throwing techniques (Osoto-gari and Ouchi-gari) in this study.

Rotational acceleration is suspected to play another role in causing sports head injuries. It is unlikely that head acceleration in response to a judo throw

is isolated to either translational or rotational acceleration. However, the data from the US National Football League demonstrated that there is a linear correlation between translational and rotational acceleration.¹²⁾ Future studies will measure the rotational acceleration of judo throwing techniques.

We propose that using an under-mat is a simple strategy to reduce the head impact force experienced in judo. Modification of rules is one approach that has met with previous success in reducing injuries in some sports.⁷⁾ However, this strategy does not require a change in rules and will not reduce the enjoyment and health benefits associated with judo. Further clinical trials are required to prospectively examine the prevalence of head injuries of judo using an under-mat.

Acknowledgment

The authors gratefully acknowledge Honda R&D (Haga, Tochigi) for supporting the experiment.

Conflicts of Interest Disclosure

There are no conflicts of interest for all authors. Masahiro Ogino who is member of The Japan Neurosurgical Society (JNS) have registered online Self-reported COI Disclosure Statement Forms through the website for JNS members.

References

- 1) Akiyama A, Okamoto M, Rangarajan N: Development and application of the new pedestrian dummy. *ESV Paper* 463: 1–12, 2001
- 2) Hertz E: A note on the head injury criterion (HIC) as a predictor of the risk of skull fracture. *in AAAM (eds): 37th Annual Proceedings of the Association for the Advancement of Automotive Medicine*. San Antonio, Association for the Advancement of Automotive Medicine, 1993, pp 303–312
- 3) Hirakawa K, Hashizume K, Fuchinoue T, Nakamura N: [Patterns of craniocerebral injuries caused by sports]. *No Shinkei Gaisho* 3: 579–586, 1971 (Japanese)
- 4) Kerrigan JR, Murphy DB, Drinkwater DC, Kam CY, Bose D, Crandall JR: Kinematic corridors for PMHS tested in full-scale pedestrian impact tests. *in NHTSA (eds): Proceedings of the 19th Conference on the Enhanced Safety of Vehicles (ESV)*. Washington, DC, United States Department of Transportation National Highway Traffic Safety Administration, No. 05-0394, 2005
- 5) Kujala UM, Taimela S, Antti-Poika I, Orava S, Tuominen R, Myllynen P: Acute injuries in soccer, ice hockey, volleyball, basketball, judo, and karate: analysis of national registry data. *BMJ* 311: 1465–1468, 1995
- 6) Langlois JA, Rutland-Brown W, Wald MM: The epidemiology and impact of traumatic brain injury: a brief overview. *J Head Trauma Rehabil* 21: 375–378, 2006
- 7) McPherson M, Pickett W: Characteristics of martial art injuries in a defined Canadian population: a descriptive epidemiological study. *BMC Public Health* 10: 795, 2010
- 8) Nagahiro S, Mizobuchi Y, Hondo H, Kasuya H, Kamitani T, Shinbara Y, Nimura Y, Tomatsu T: [Severe head injury during Judo practice]. *No Shinkei Geka* 39: 1139–1147, 2011 (Japanese)
- 9) Nishimura K, Fujii K, Maeyama R, Saiki I, Sakata S, Kitamura K: Acute subdural hematoma in judo practitioners—report of four cases. *Neurol Med Chir (Tokyo)* 28: 991–993, 1988
- 10) Pellman EJ, Viano DC, Tucker AM, Casson IR, Waeckerle JF: Concussion in professional football: reconstruction of game impacts and injuries. *Neurosurgery* 53: 799–814, 2003
- 11) Pieter W: Martial arts injuries. *in Caine DJ, Maffuli N (eds): Epidemiology of Pediatric Sports Injuries: Individual Sports (Medicine and Sport Science) 48*. Basel, Karger, 2005, pp 59–73
- 12) Schmitt K-U, Niederer PF, Muser MH, Walz F: *Trauma Biomechanics, ed 3*. Heidelberg, Springer, 2010
- 13) Spinks AB, McClure RJ: Quantifying the risk of sports injury: a systematic review of activity-specific rates for children under 16 years of age. *Br J Sports Med* 41: 548–557, 2007
- 14) Thurman DJ, Branche CM, Sniezek JE: The epidemiology of sports-related traumatic brain injuries in the United States: recent developments. *J Head Trauma Rehabil* 13: 1–8, 1998
- 15) Versace J: A review of the severity index. *in SAE (eds): Proceedings of the 15th Stapp Car Crash Conference*. New York, Society of Automotive Engineers, 1971, pp 771–796

Address reprint requests to: Haruo Murayama, MS, Department of Sports Science, Dokkyo Medical University, School of Medicine, 880 Kita-kobayashi, Mibu, Tochigi 321-0293, Japan. e-mail: hmurayam@dokkyomed.ac.jp