4. 大外刈のバイオメカニクス

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4. The Biomechanics of Osoto-gari

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要約
これまでに柔道の技について解説した多くの著物があるが、技を定量的に分析した研究はまだ
まだ少ない。我々は、バイオメカニクス的分析は技の本態を定量的に解明するために役立つ
と考えている。そこで、本研究の目的は柔道の柔能制覇という理解をふまえて、大外刈をバイ
オメカニクス的用法で分析することである。
これまでに行ってきた3つの柔道のバイオメカニクス的分析における大外刈の解析データを利
用し、大外刈の投げをバイオメカニクスの観点から再考した。結果は以下の通りであった。
A. 取の分析
1) 割り足の足関節の形について：割り足の速度、即ち股関節の角速度は足関節の屈屈位と背
屈位では差がなかった。また、屈屈位と背屈位とも割る時には膝関節の動きが伴ったことか
ら、割り足は足関節の屈伸に関わらず、むしろ膝関節の動きを用いた鞭的な効果（キネティ
ックリングパターン）を発揮するような動作が重要であると考えられる。
2) 熟練者（有段者）と未熟練者（無段者）の大外刈の比較について：熟練者ではピーク角速
度が股関節、膝関節、足関節の順に現れた。そして、熟練者の足関節の屈曲速度のみが未熟
練者と比較して速かった。これは、熟練者は割り足を一本の棒（剛体）とするのではなく、
鞭効果を利用してような動作をしているからと考えられる。一方、股関節と膝関節の角速度
には差はなかったが、熟練者の体幹の速度は有意に大きかった。このことから、取にとって
は割り足よりも受に上体を含むさせる体幹の動きが重要であると考えられる。
3) 取の重心は、崩し・作りの局面では前方向（負）の運動量を示したが、掛けの局面で急激
に正の運動量に変化した。また、崩しの局面で上方向への重心移動は期待したほど顕著では
Judo continues to be one of the most popular sports in the world. Recent information from the International Judo Federation (IJF) indicated that 178 National Federations over 5 continents are currently practicing judo. Since its inauguration into the Summer Olympic Games in Tokyo (1964), the popularity of judo has grown and has attracted worldwide attention as a competitive international sport.

Despite its amenity to biomechanical analysis, few studies concerning the biomechanics of judo have been written in English (Harter & Bates, 1985; Imamura & Johnson, 2003; Minamitani, Fukushima, & Yamamoto, 1988; Pucskok, Nelson, & Ng, 2001; Serra, 1997; Sacripanti, 1989; Tezuka, Funk, Purcell, & Adrian, 1983). The osoto-gari (major outer leg reap) is one of the most popular throwing techniques used by judo competitors. Despite its simplistic nature, many experts consider the throw easily learned but very difficult to master (Daigo, 1994; Yamashita, 1991).

From a qualitative perspective, a successful osoto-gari is executed when tori (thrower) creates simultaneous pushing and pulling forces onto the body of uke (faller). The pushing force is directed towards the upper body of uke, while the pulling force (from tori’s sweep) is directed towards the lower body. These forces produce a rotational motion onto the body of uke, a motion much like that of a pinwheel (Figure 1). Most experts agree that an effective rotation of uke’s body is a clear reflection of the throw’s success (Daigo, 1994; Yamashita, 1992).

Biomechanical analysis of osoto-gari is necessary to develop a greater understanding of the mechanical nature behind the throw, which up to now has been studied mostly through qualitative means. The following is a quantified presentation of some of the biomechanics underlying the osoto-gari throw, with an emphasis on factors that contribute to judo’s general philosophy of “maximum efficiency with minimal effort”.

Methods

The biomechanical data that were reviewed for this manuscript originated from video motion analysis (Imamura, 1996; Imamura & Johnson, 2003; Imamura, Hreljac, Escamilla, & Edwards, 2004). All video footage was collected at 60 Hz. All throws were executed to insure a combination of maximal effort and proper technique by tori under non-competitive situations (nagekomi). In addition, no conscious resistance by uke was given during the throws. A Peak Performance Inc. Motus motion analysis software (Englewood, CO, USA) was used to determine kinematic variables such as angular velocities for hip, knee, and ankle joints in two-dimension and location of center of mass as well as linear velocities of the center of mass in three-dimension. Statistical analysis used for the Imamura and Johnson (2003) study was a one-way MANOVA (p=.05) to determine dif-
ferences between black and novice groups.

Kinematic Analysis of Tori

The osoto-gari throw, as well as all throws in judo, are separated into phases. The founder of modern judo, Jigoro Kano (1860–1838), developed phases with the intent of developing judo through analytical thinking. There are three main phases: kuzushi is the preparatory phase defined as breaking an opponent’s balance or simply to prepare them for a throw, tsukuri is the process of fitting into the throw, and kake is the acceleration phase describing the execution of the throw itself. For the osoto-gari throw, kuzushi begins with the onset of tori’s leg drive from the sweeping (right) leg, allowing the supporting (left) leg to move towards uke and ends with tori’s sweeping leg moving up to uke’s body. Tsukuri immediately follows kuzushi and begins with tori’s sweeping leg passing uke’s body and ends with tori’s sweeping leg making sweep contact. Kake immediately follows and begins with sweep contact to uke’s body and uke’s legs subsequently striking the ground. Figure 2 illustrates the different phases of osoto-gari.

There has been much attention given to the sweeping aspect of osoto-gari. Imamura (1996) and Imamura and Johnson (2003) studied two-dimensional peak angular velocities of tori’s sweeping leg just prior to contact as well as peak trunk angular velocities for both tori and uke. The first study by Imamura (1996) compared black belt subjects performing two different types of sweep based on foot position. The foot placed in a plantarflexed position (toes pointed downward) prior to sweep contact is considered the orthodox method while the foot placed in a dorsiflexed position (toes pointed upward) the unorthodox method (Figure 3). The unorthodox method was made famous by the legendary champion Masahiko Kimura (1917–1994) who believed that sweeping power was enhanced by dorsiflexing the foot (Daigo, 1994).

Biomechanically, Kimura’s style can potentially shorten the length of one’s sweeping leg by decreasing the moment of inertia and increasing angular velocity about the hip thereby increasing sweeping power. However, it was found that there was no significant difference in hip angular velocity between the two styles. Furthermore, it was found that subjects had a tendency to move their knee during the sweep. The knee movement altered the moment of inertia characteristics about the hip affecting the results of the study, but more importantly indicated that subjects were using the sweeping leg as a linked segment rather than a single rigid one.

Imamura and Johnson (2003) further investigated the osoto-gari two-dimensionally from the perspective that skilled judo players will use their sweeping leg not as a rigid segment but as a coordinated linked system. In this study 10 black belt subjects were compared to 10 novice subjects. The study found temporal differences in the pattern of sweep from the hip to ankle: time of peak hip extension angular velocity, time of peak knee flexion angular velocity, and time of peak ankle plantarflexion angular velocity. Figure 4 illustrates the ability of black belt subjects to create peak velocity and momentum from their larger muscles first (i.e. hip muscles) and then transferring momentum to smaller muscles of the knee and ankle in a linked fashion. In a sense, the action of the sweeping leg for osoto-gari can be compared to the action of a throwing arm for pitching where muscles are contracted in a sequential manner to obtain optimal final momentum in distal segments, a concept referred to as kinetic link.

The study also found a significant difference in peak angular velocity for the ankle but not for other joints of the sweeping leg. This indicated that the only major difference in sweep velocity between black belt and novice subjects came from the ankle, particularly plantarflexion. Thus, large plantarflexion activity during the sweep can be considered a skilled trait and perhaps a key component to a successful kinetic link system.
Other findings of the study further suggest that the *osoto-gari* sweep is not necessarily the most important aspect of the throw. While there were no significant differences in hip and knee angular velocities for the sweeping leg between novice and black belt subjects, the study did find significant difference in trunk angular velocity as *tori* made chest to chest contact or impact with *uke*. Black belt subjects were able to produce greater trunk angular velocity than novice subjects indicating that the upper body impact during *kuzushi* and *tsukuri* is a very skilled trait and should be considered important if not more important than the sweep. Table 1 presents two-dimensional average angular velocities for black belt subjects executing *osoto-gari*.

A three-dimensional analysis of *osoto-gari* was performed by Imamura, Hreljac, Escamilla, and Edwards (2004) to investigate the center of mass (CM) momentum for both *tori* and *uke* during *kuzushi* and *tsukuri*. Four black belt subjects served as *tori* for this study, while a different black belt subject was used as *uke* and accepted the throws for all subjects. The study was able to determine forward-backward (x), up-down (y), and side-to-side (z) momentum for *tori* and *uke*.

As would be expected, *tori* was found to increase forward momentum from *kuzushi* to *tsukuri* phases as *uke* is pushed backwards. This momentum continues to increase until *kake* where it decreases sharply and changes direction. The abrupt change in forward to backward momentum is due to the collision created by the upper body impact between *tori* and *uke*. This is consistent with previous findings of Imamura and Johnson (2003) who found large peak trunk angular velocities for *tori* during *osoto-gari*.

Within the up-down direction, *tori*’s momentum was found to move slightly upward during *kuzushi* and then slightly downward during *tsukuri*. From a biomechanical standpoint one would expect *tori* to lift *uke* upward to reduce frictional resistance from *uke*’s feet prior to sweep contact. Though momentum values did indicate upward momentum during *kuzushi*, they were considered relatively small with high variance. Therefore, two assumptions can be made. The first is that upward momentum for *tori* during *kuzushi* may not be as important as one would expect and, second, whether it is important or not, upward momentum is most likely influenced by the relative height of *uke* and *tori* and should be accounted for in future studies.

Within the side-to-side direction, *tori* was found to direct their momentum towards the pulling hand for both the *kuzushi* and *tsukuri* phases. This is expected as most judo players will pull *uke* sideways so that *uke*’s weight is shifted onto the leg that will be swept. Figure 5 illustrates all directional average momentum and standard deviation for *tori* during *osoto-gari*.

Kinematic Analysis of Uke

Analyzing *uke*’s motion can be viewed as analyzing the product of *tori*’s throw. Furthermore, it can reveal the position and movement of *uke* prior to the throw and likewise further investigate the meaning of *kuzushi* and *tsukuri*. Three-dimensional analysis indicated that *uke*’s CM had forward and upward momentum and momentum towards the pulling hand during the *kuzushi* phase. The *tsukuri* phase indicated a continuation of forward and upward momentum as well as momentum towards the pulling hand, while *kake* depicted momentum backwards, downwards, and away from *tori*’s pulling hand.

Since the *osoto-gari* tosses the *uke* backwards, one would expect *uke* to move backwards in all phases. However, this was not the case as *uke*’s momentum increased from *kuzushi* to *tsukuri* in the forward direction. It was not until *kake* that *uke* moved backwards. From these results, it is likely that *tori* pulls *uke* towards them while stepping into the throw during both *kuzushi* and *tsukuri*. The results for *tori* also demonstrated forward momentum indicating a prelude to a collision between *tori* and *uke*. Similar to what was seen in *tori*’s momen-
tum was a sharp change in uke’s momentum following body impact. This once again indicated an importance for tori to create a large collision or impact onto uke.

Uke’s forward momentum during kazushi and tsukuri can be attributed to uke’s reaction to tori’s push, a concept referred to as “reaction resistance”. Reaction resistance occurs as a result of uke attempting to maintain balance during the kazushi phase. This is most likely a subconscious movement by uke thus the term “reaction resistance”. It is thought that “reaction resistance” is a necessary occurrence during kazushi, in that, without a slight resistance from uke, tori cannot perform tsukuri very well. Therefore, it is also possible that uke creates a slight resistance reaction to tori’s push which allows tori to properly fit into the throw. Furthermore, it is likely that some form of reaction resistance occurs during every throw during the kazushi phase.

Imamura and Johnson (2003) indicated very little movement of uke in the up-down direction during osotogari. The three-dimensional study indicated a pattern of upward momentum during the kazushi and tsukuri phases, however the values were small with a large variance. This substantiates previously mentioned findings with CM momentum results of tori, in that, uke’s upward momentum does not seem to be an important aspect of the throw. However, it should be emphasized that height differences between tori and uke were not taken under account with these measurements and could have affected the results.

Within the side-to-side direction there was no indication of a “resistance reaction” from uke. Rather uke’s body moved towards tori’s pulling hand with the greatest momentum being created during the tsukuri phase. Thus, tsukuri tends to be a particularly important phase for this throw. This is in agreement with Imamura and Johnson (2003) who found chest to chest contact and upper body angular velocity to be an important aspect of osotogari. Figure 6 illustrates all directional average momentum and standard deviation for uke during osotogari.

Conclusion

The osotogari is comprised of tori generating two forces onto the body of uke. The first force targets the upper body, pushing uke backwards. The second force targets uke’s leg, sweeping the lower body forward. When these forces are successfully integrated uke’s body rotates about its center and falls to the ground.

There has been much attention given to the osotogari sweep (major outer leg reap) as the name implies. Research has found that the sweep is a skilled trait. Experienced judo players (black belts) have developed the skill to use their sweeping leg as a linked system to build optimal momentum via kinetic chain. In particular, experienced players are much more active with ankle plantarflexion than novice players in an effort to maximize all segments and muscles of the leg.

Research has also indicated that the osotogari sweep may not be the most important aspect of the throw. Experienced judo players will use upper body impact or collision to push uke backwards and towards their pulling hand. While novice players were shown to exhibit similar angular velocities of the sweeping leg as compared to experienced players, they were considered very poor in creating upper body velocity and impact. Because impact is a very important aspect of osotogari, it is important that judo players develop large momentum prior to the kake phase. Likewise, individuals that are heavy and fast are likely to produce the best momentum necessary to execute osotogari well.
References


図2. 大外刈の3つの主要局面：崩し・作り・掛け  Imamura, R.T., et al. (2004) から引用

Figure 3. Two styles of osoto-gari sweep, a) orthodox style with the toes pointed outward and ankle plantarflexed b) unorthodox style with toes curled-up and ankle dorsiflexed.

図3. 大外刈の刈り足の2つのスタイル；a）足関節底屈位でつま先を伸ばした標準的なスタイル，b）足関節背屈位でつま先を上に向けた特別なスタイル
Figure 4. Typical sweep pattern for a black belt subject depicting a kinetic link pattern.

Table 1. Mean, standard deviation, and significance values (p<0.05) for the following variables: peak tori angular velocities for trunk flexion (TTRK), hip extension (THIP), knee flexion (TKNEE), and ankle plantarflexion (TANK); peak uke angular velocities for the trunk (UTRK) and leg (ULEG) with respect to the vertical axis.


<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>N</th>
<th>Mean (deg/s)</th>
<th>Std. Deviation</th>
<th>Probability Values</th>
</tr>
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<tr>
<td>THIP</td>
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<td>10</td>
<td>508.26</td>
<td>50.70</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>novice</td>
<td>10</td>
<td>435.79</td>
<td>126.36</td>
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<tr>
<td>TKNEE</td>
<td>black belt</td>
<td>10</td>
<td>833.29</td>
<td>127.89</td>
<td>0.453</td>
</tr>
<tr>
<td></td>
<td>novice</td>
<td>10</td>
<td>756.47</td>
<td>289.52</td>
<td></td>
</tr>
<tr>
<td>TANK</td>
<td>black belt</td>
<td>10</td>
<td>746.74</td>
<td>134.63</td>
<td>0.011 *</td>
</tr>
<tr>
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<td>novice</td>
<td>10</td>
<td>552.49</td>
<td>169.87</td>
<td></td>
</tr>
<tr>
<td>TTRK</td>
<td>black belt</td>
<td>10</td>
<td>334.69</td>
<td>35.92</td>
<td>0.043 *</td>
</tr>
<tr>
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<td>novice</td>
<td>10</td>
<td>299.37</td>
<td>36.78</td>
<td></td>
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<tr>
<td>UTRK</td>
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<td>394.14</td>
<td>117.33</td>
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<td>284.32</td>
<td>57.31</td>
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<td>ULEG</td>
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<tr>
<td></td>
<td>novice</td>
<td>10</td>
<td>608.78</td>
<td>133.99</td>
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</table>
Figure 5. Tori’s directional momentum (forward-back(x), up-down(y), side-to-side(z)) for three phases (1 = kazushi, 2 = tsukuri, 3 = kake) of osoto-gari. Tori’s forward and left side momentum are considered negative in this case.

図5. 廃し・作り・掛けの3局面における取の重心の運動量（前後（x）、上下（y）、横（z））。取からみて前方向と左方向の運動量が負となる

Figure 6. Uke’s directional momentum (forward-back(x), up-down(y), side-to-side(z)) for three phases (1 = kazushi, 2 = tsukuri, 3 = kake) of osoto-gari. Uke’s forward and left side momentum are considered positive in this case.


図6. 廃し・作り・掛けの3局面における受の重心の運動量（前後（x）、上下（y）、横（z））。受からみて前方向と左方向の運動量が正となる。Imamura, R.T., et al. (2004) から引用