The Course of Our Ski Research

スキー研究の軌跡

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Summary
Skiing as a sport has been the subject of studies of its various aspects, including instruction, injury treatment, improvement of equipment and sliding mechanisms. Among them, from the viewpoint of the clarification of the mechanisms of ski turns, we describe the history of skiing, and examine several issues relating to research on the ski. In addition, we demonstrate that, based on the results of our research, (1) ski turns are determined by the edging angle β_0, and (2) the skier's sense of making a ski turn is an illusion.

Key words: ski, sense of making a ski turn, edging angle

1. Introduction: History of skiing

Tools equivalent to present-day skis used as a means to support daily life have been discovered in snowy regions of various countries worldwide. We can currently see them as objects excavated from historic remains, or in the form of traditional footwear. The Japanese "*Kanjiki (snowshoes)*" is one example. We will follow the history of skiing with reference to the textbook by the Ski Association of Japan.[3]

The first example of skiing which was not essential to daily life may be the ski squad established as part of the Norwegian army in 1740. Skiing became the national sport of Norway in 1867, and subsequently became widely accepted as a sport. The techniques of skiing were systematized and spread to nearby countries. Around the same time, while skiing in Norway was performed on flat ground, mountain skiing was arose in Austria; a textbook of the Austrian skiing technique was published in 1896. In this skiing technique, ski turns were controlled by a single pole held in the skier's hand. This turning technique is called the snow plow or stem plow; it was introduced to the army of Northern Japan by LERCH of Austria in 1911 (the Proceedings of the Fourth Meeting of the Japan Society of Ski Sciences, 1994, refer to the cover). In 1924, the first Winter Olympic Games were held in Austria. At that time, the stem plow and stem turns were utilized as skiing techniques. The parallel turn was established in Austria in 1930. The parallel-turn technique is demonstrated by SCHNEIDER in the Proceedings of the Second Meeting of the Japan Society of Ski Sciences, 1992 (refer to the cover). Only slight differences are seen in the skiing equipment and skiing style between SCHNEIDER and current skiers. Skiing has become commonplace and various technological discussions have been made. In 1938, the rotation technique was introduced in France, and the wedeln technique in Austria in 1955.

After World War II, during the era of rapid economic growth in Japan, many ski resorts were constructed in various regions, and the number of skiers increased. Around this time, parallel turns and wedeln were introduced to the Japanese people through movies from Europe. Those who saw these techniques were greatly impressed by the splendid and elegant style of ski descents, and many people were attracted to snowy mountains. However, it is not easy to accomplish

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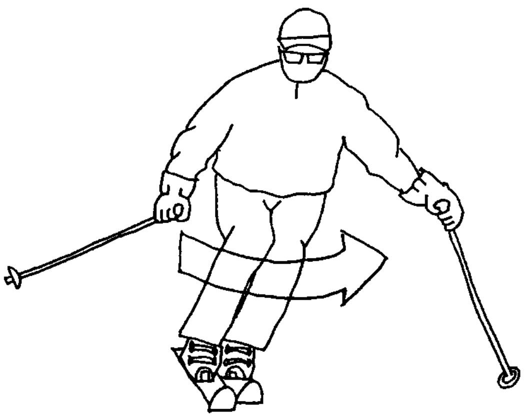

Fig.1 Rotation: Skier's motion to turn the skis using his/her muscular strength (twisting of the knees). (Japan Ski Kyotei, 1994).

parallel turns and wedeln. Many ski classes were held at ski resorts, and some people attempted to physically clarify the mechanisms of ski sliding.

The major ski-sliding techniques are (1) straight descent and (2) turning descent. Straight descent is relatively easy to accomplish, although descending speed may differ depending on each individual. For example, almost anybody can accomplish a straight descent under appropriate slope conditions after a few lessons. However, even if they can perform a straight descent, they may not be able to stop. Straight descent can be compared to a car engine, and turning descent to a brake. Turning techniques such as snow plow, parallel turn and wedeln are classified as turning descents. Without acquiring turning-descent techniques, the ski-sliding technique is not complete. Therefore, the main task for skiing instructors is to teach how to perform turning descents. The ski-sliding technique predominantly involves the turning descent.

2. Turning-descent technique

The snow plow was the turning-descent technique which I was first taught. This technique can be acquired within a day if skiing conditions are appropriate. Alternate motions of the right and left feet are all that is required to accomplish turning descents to the right and to the left. I could almost visualize the principle of this turn, and it was not a difficult technique to master. However, good skiers perform turning descents with their knees aligned, by moving both feet simultaneously right and left. This is a very attractive-looking descent, but it was very difficult for me to imitate the motion. This turning-descent technique is called the parallel turn. I once saw a skier who could perform parallel-like turns on one foot.

The parallel-turn technique can be mastered after a number of drills based on imitation. When we are able to perform parallel turns, many of us often wonder, "*In the past, I could not make my skis turn when I twisted my body, but now when I twist my body only slightly, the skis turn in the direction of twisting. Why is that so ? What is the difference between what I did then and what I do now ?*" This is reflective of a skier's honest impression of performing ski turns.

There exist other turning techniques similar to the parallel turn. Among them, the mechanisms of jump turns and step turns are easy to understand. Parallel turns and one-foot turns are difficult to understand, because both feet make the same motion simultaneously, without jumping or up-and-down motions. Hereafter, I will focus on the parallel-turn technique.

This turning-descent technique (parallel turn) seems to be understood as follows: when a skier (on skis) twists his body in the direction of the desired turn, the skis turn in that direction. Similarly, many skiers perceive that the skis turn towards the direction of the body twist.

Reflecting back on the history of skiing, we see that when the rotation technique (established in France in 1938) was used, the skier twisted his body considerably in the direction of the desired turn. This is a large motion described as "*bowing while twisting the body.*" In rotation sliding, the length of right and left turning-descent arcs was 4~6 or more times longer than the length of the skis. Subsequently, the wedeln technique was established in Austria. In wedeln, the length of right and left turning-descents arcs is similar to the length of the skis, and the time required for a turn is short. Accordingly, large motions such as a bow are impossible; while fixing the upper body so as not to rotate, the waist and knees are twisted quickly with small motions.

According to the Beinspiel theory,[3] the upper body is twisted in the opposite direction in a wedeln turning descent. However, when observing the wedeln sliding, the upper body is always facing the fall line and only the knees and skis move right and left alternately. To the best of our knowledge, there is no sliding descent in which skis faces right while the upper body faces left. Namely, reverse (or opposite) twisting does not mean that the upper body is twisted in the direction opposite to the turn, but means that only the lower body is twisted in the direction of the turn while the upper body is fixed so as not to rotate. Reverse twisting may be

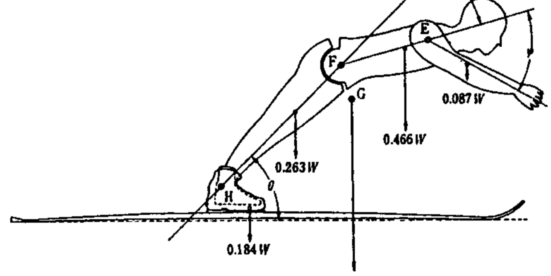

Fig.2 Dummy in the tunnel experiments of ski jump (from TANI, 1951).

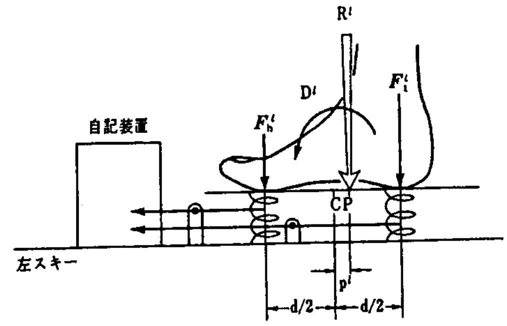

Fig.3 Automatic measurement recording of the pressure applied to the sole of the skier's foot (from NISHIWAKI,1971).

an issue of the skier's perception.

According to the textbook by the Ski Association of Japan,[4] turning descents with short sliding loci (wedeln) are called short turns, and those with long sliding loci (parallel turns) are called long turns. The skier's motion to turn the skis by twisting his/her waist or knees is called rotation (Fig.1). It is explained that skiers turn the skis using rotation motions in short and long turns. Usually, various motion factors other than rotation motion are considered for ski turns. In the textbook,[4] edging and loading are indicated as other motion factors.

Thus, in any textbook of any era, common skiing techniques of turning descent seem to dictate that "*in order to turn skis, skiers twist their body in the direction of turning.*"

3. Ski research

Various types of research relating to skiing are conducted. (1) Research on skiing instruction regarding how to teach turning descent, (2) research on the treatment of injuries since injuries inevitably accompany sports, (3) engineering research relating to the improvement of ski equipment, (4) scientific research on the clarification of the mechanisms of ski sliding, (5) other research from the viewpoints of competition, management, sociology, psychology and literature.

Here, we review the studies on skiing focusing on the clarification of ski-sliding mechanisms. In 1939, the English physicist BOWDEN[1] studied frictional resistance during skiing. The coefficient of friction of a snow plane is approximately 1/10 smaller than that of most materials. He explained this smaller value using a theory of snow melting on a snow plane due to frictional heat. In 1951, the aerobic engineer TANI[5] performed wind tunnel experiments of ski jumps (Fig.2). He described the relationship between the body shape of a jumper and the jumping distance in his book titled "Aerodynamics of Ski Jump." In 1955, KINOSITA, a physicist, performed measurement of the straight descent,[2,5] and obtained the coefficient of air resistance of a skier and the coefficient of friction of snow. In 1956, NISHIWAKI, an engineer, measured the pressure applied to the feet of a skier (Fig.3).[5] He placed four pressure gages between the sole of the skier's foot and the skier's boot (left and right feet; total of eight pressure gages). He found that 70% of the pressure was applied to the outer foot of the skier at the time of turning. In 1965, the physicist OHNISHI compiled detailed data from research conducted between 1955 and 1960.[6] In 1971, KINOSITA explained ski turns using a side cut (curve) of a ski and rotation.[2] In 1979, the gymnastics researcher SODEYAMA experimentally demonstrated the changes in the center of gravity of a skier on a mogul during skiing on a straight slope with moguls (Fig.4)[11]. In 1985, the gymnastics researcher SHIMIZU began sliding experiments using a ski robot.[10] SHIMIZU modified and improved the robot, and proposed that a skier's turns can be explained by the sliding method of turns made by the robot. However, no experiments which quantitatively explain the similarity between skier's turns and robot turns have been performed.

4. Problems in ski research

As described in Section 2, in skiing technique theory, it is usually considered that "*skis are turned by twisting the body.*" If "*the direction in which the body is twisted and the resulting direction of a ski turn are identical,*" then it is contradictory to the law of conservation of angular momentum. It is impossible for skis to turn in the direction of a body twist. This theory, which is contradictory to the laws of physics has been accepted for a long time, and the theory of ski turns was established and the instruction of skiing has been performed based on this theory. There have been no researchers who have attempted to tackle this enigmatic issue.

The studies by KINOSITA[5] and SODEYAMA[11] concern straight descents. The study by NISHIWAKI[5] examined turning descents, but the method of drawing

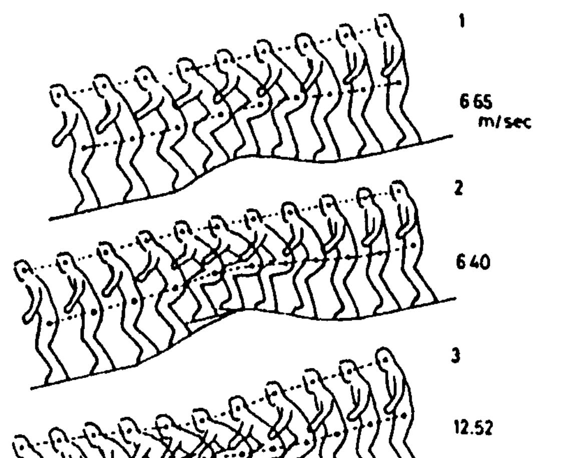

Fig.4 Change in eye position and center of gravity of a skier when passing through a mogul. (from SODEYAMA, 1979).

turning tracks which illustrate skier's loci was not very clear. This was because no method of quantitatively recording the loci of a turning descent of a skier had yet been established.

The first step in elucidating skiing dynamics regarding the turning descent is to obtain data regarding the skier's position at a specific time during a turning descent, namely, the relationship between time and position of the skier. These data can provide values for speed, acceleration and coefficient of friction during the turning descent, yielding clues to clarifying the skier's motion.

5. Start of our research

We started our ski research in July 1983. In the initial stage of the study, the important thing was to observe ski motions. Accordingly, it was necessary for us to be able to easily observe ski motions in our laboratory. In place of snow on a ski area, we considered that a substance which was stable against temperature and humidity changes would be required. Therefore, we used sand. The sand was obtained from a playground, was well dried under the summer sun and sieved through a 0.5-mm sieve. It was pure and beautiful dried sand similar to that in an hourglass. A ski area was modeled with a box of $180\times80\times5$ cm^3, in which the sand was placed (Fig.5). To obtain a perfectly planar surface, the box was placed on a ping-pong table. One end of the table was placed directly on the floor, and the other side was lifted by a special jack to create a slope. As the ski, a 0.8-mm-thick vinyl chloride plate with a size of 2×19 cm^2 was used (Fig.6). An aluminum cylinder was placed at the center of the ski, and an iron plate was placed on the cylinder. Magnets were placed on the iron plate to enable loads on the ski to be changed. We performed repeated preliminary examinations on ski descent, varying the position and weight of the loads. We found that stable data regarding temperature and

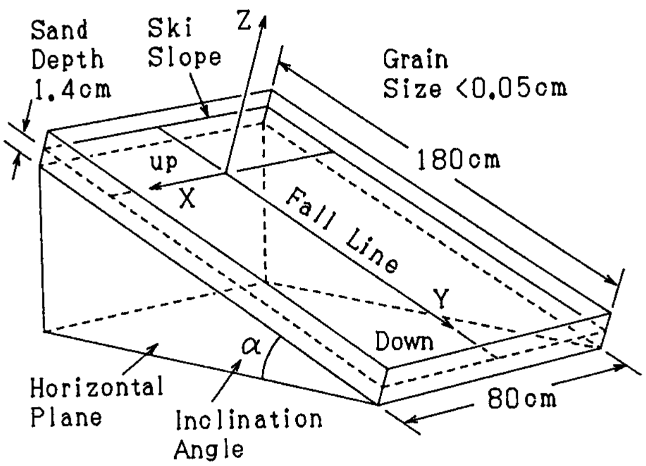

Fig.5 Model of a ski slope using sand instead of snow in the laboratory. *Y*; the fall line, *Z*; axis perpendicular to the sand plane, *X*; axis perpendicular to both *Y* and *Z* axes.

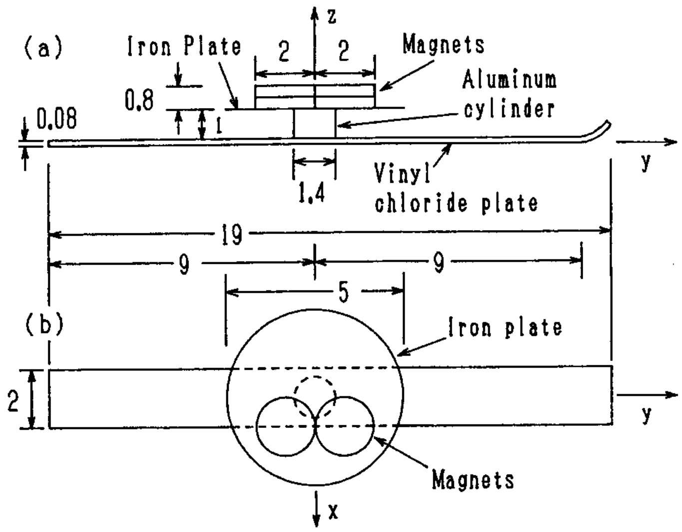

Fig.6 Straight ski.
y; axis parallel to the ski length,
z; axis perpendicular to the ski surface,
x; axis perpendicular to both *y* and *z* axes.

humidity could be obtained. We performed 3000 descents in a preliminary experiment. As the number of descents increased, the sand became packed; therefore we loosen the sand to make it as before. We found that the effects of packed sand must be considered in the experiments. Figures 5 and 6 show the coordinate axes of the experimental ski area, (*X*, *Y*, *Z*),[8] and the coordinate axes of the ski (*x*, *y*, *z*).[8]

6. Observation of sliding ski

We performed ski-sliding experiments using a model ski on a sand plane, varying the position of the magnet on the ski. The position of the magnet was changed in the direction (A_1) of the length of the ski, *y*; (A_2) perpendicular to the ski, *z*; (A_3) perpendicular to both *y* and *z* directions, *x*. The directions of observation were (B_1) perpendicular to the slope, *Z*; (B_2) in the direction of *X*; (B_3) in the direction of sliding ski and viewed from the front, θ (Fig.8).[8] The method of observation is as follows. (C_1) The sliding ski is continuously photographed by a camera, and the relationship between the position of the ski and the time during the ski descent is analyzed using the photographs. (C_2) After the ski-sliding, the position of the ski locus on the sliding plane is examined. (C_3) Using a transparent ski made of the same material and with the same shape as the above model, the range of contact of the ski surface with the sand is examined.[7] The cameras used to take the continuous photographs are (D_1) a still camera with 35-mm-film (Fig.7) and (D_2) a video camera.

As described above, we observed, recorded and analyzed the sliding ski from various directions using various methods. Some of the results are introduced here.

(1) First, we observed the ski from the *Z* direction (B_1), which is perpendicular to the slope, while varying the center of gravity of the ski in the *x*