DIFFERENCES AMONGST BONE, SKIN, AND SKATE MARKER-BASED ROTATIONS OF THE FOOT DURING PUSH-OFF IN SKATING

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The present study aims at exploring differences amongst bone, skin, and skate marker based rotations of the foot during skating. A vector that passes through two markers on the bone, a vector that passes through two markers on the skin, and a vector that passes through two markers on the skate were used to represent foot rotations from dorsiflexion to neutral position and from neutral position to plantar flexion based on bone, skin, and skate markers. Paired samples t-tests were used to compare the rotations of different vectors to each other. The results showed that a significant difference amongst bone, skin, and skate rotations existed during plantar flexion but not during dorsiflexion. This significant difference extended to the total motion from dorsiflexion to plantar flexion where skate rotations were 26% smaller than bone rotations and 49% smaller than skin rotations. Bone rotations were 31% smaller than skin rotations. Based on the results of this study, it can be concluded that, unlike shoe motion, the rigidity of the skate structure causes the skate motion to underestimate the motion of the underlying bony and skin structures.

KEY WORDS: X-ray, 3D analysis, Hockey, bone, skate.

INTRODUCTION: In filming and digitizing human segmental motion, external markers do not necessarily represent a true picture of the actual bone movement. When surface markers are placed on the skin or skate boot (in ice hockey) they move according to skin or boot movement, which does not exactly match bone movement. This results in a misrepresentation of the joint axes of rotation and a greater margin of error in motion measurement and analysis. This problem occurs for ankle and foot movements as their motion is quantified about the ankle joint complex (talocrural and subtalar joints). Variability amongst bone, skin, and shoe markers has been identified in the works of Reinschmidt (1997). He concluded that markers placed on the shoe tend to overestimate tibiocalcaneal rotations. However, hockey skates are vastly more rigid than regular shoes and their restriction of foot movement is greater. Therefore, shoes and hockey skates cannot be considered identical. The present study aims at exploring differences amongst bone, skin, and skate marker based rotations of the foot during skating.

METHODS: Five healthy male university students participated in the study. All subjects had size 9 feet and were skilled skaters with no morphological deformations or anomalies of the lower leg or feet. *Altered Skate:* Three openings of 2cm diameter were made, in a manner that preserved structural integrity, in a right hockey skate in the area above the tarsus of the foot. Three 5mm lead spheres were covered with reflective tape and fixed on top of plastic screws to serve as skin markers that will protrude through the openings in the skate. Another three markers were attached to the body of the skate in non-coplanar locations. These markers represented the motion of the skate boot. *X-ray Calibration Cage:* A 50x50x50 cm Plexiglas calibration cage was constructed for the x-ray measurements. The cage included a movable platform for the foot while in the skate. The platform rested on a 20cm-high fulcrum, made of Plexiglas and fixed at mid point of the floor of the cage, which allowed it to move freely. It also had two holes in the front and the back for two Plexiglas bars that extended to the sides of the cage. Those two bars went through holes made in the side of the cage at previously determined positions that corresponded to full dorsiflexion, neutral position, and full plantar flexion with 45° of external rotation. The superior aspect of the cage consisted of two mobile sheets of Plexiglas with each having a half circular area cut off and padded to fit around the shank of the subject and prevent movement. Eighty-five lead spheres of 2mm diameter were embedded in the front and back sides of the calibration cage (34 in the front and 51 in the back). The three dimensional coordinates of the spheres were measured in relation to an origin in the right front-lower corner of the cage and were used as control points for the three-dimensional reconstruction. *Procedures:* An x-ray source was placed facing the right lateral side of the subject's foot and the x-ray film was attached to the opposite side of the Plexiglas box. Two films were exposed for each of three positions of the foot; full dorsiflexion, neutral, full plantar flexion with 45° of external rotation. The angles were chosen to simulate a push off phase in forward skating motion (Minkoff et al 1994). The x-ray source was placed in a horizontal position, 0° in relation to the platform, for the first exposure. The second exposure was at a 30° angle with the first one. *Data processing:* Two x-ray images for each of the foot positions (dorsiflexion, neutral, plantar flexion) were scanned into the computer. Markers representing bone, skin and skate were digitized on the two views of each position using APAS. The centres of spherical bony structures of the head of the talus, the body of the talus, and the cuboid bone were selected as invariant points on both images and were used to represent the motion of the bone (Allard, Stokes, Blanchi, 1995). The three dimensional coordinates of bone, skin, and skate markers were obtained for each of the foot positions using the DLT algorithm incorporated in the transformation procedure in APAS. Using vector cross product, the rotations of a vector that passes through two bone markers, a vector that passes through two skin markers, and a vector that passes through two skate markers (Figure 1) were calculated from the neutral position to dorsiflexion and from neutral position to plantar flexion. A paired samples t-test was used to compare the rotations of the foot to each other.

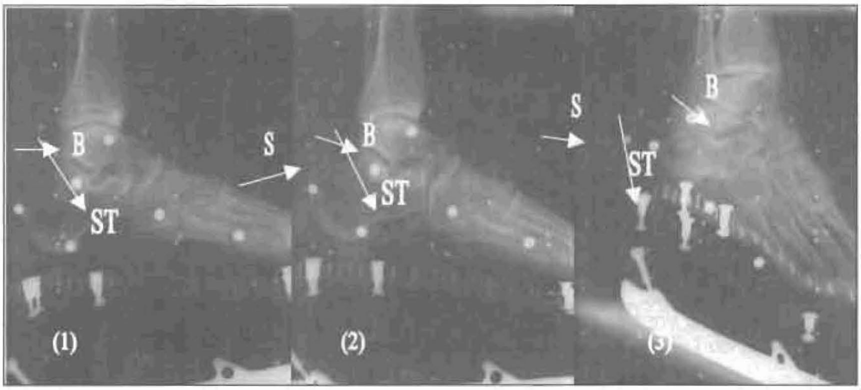

Figure 1. Foot rotations based on bone (B), skin (S), and Skate (ST) markers at dorsiflexion (1), neutral position (2), and plantar flexion (3).

RESULTS AND DISCUSSION: Table 1 shows that bone, skin, and skate rotations from dorsiflexion to neutral position did not follow a regular pattern across all subjects and the difference between them was not significant ($p>0.05$ in table 2). Rotations from neutral position to plantar flexion exhibited a regular pattern across all subjects, where skin rotations were the largest and skate rotations were the smallest (Table 1). Mean skin rotations were 42% larger than mean bone rotations and the difference between them was significant ($p<0.05$ in table 2), indicating that skin motion overestimated the underlying bone motion. However, mean skate rotation was 27% smaller than mean bone rotation and 57% smaller than mean skin rotation with $p<0.05$ (Table 2), which means that skate motion underestimated bone and skin motions. Furthermore, data in table 1 show that skate and bone rotations from neutral position to plantar flexion were systematic across all subjects (skate rotations about 70% of bone rotations) except for subject 2. This might suggest the existence of a predictive relationship between the two motions that need to be explored with a larger sample size.

Table 1. Bone, skin, and skate vectors' rotations from dorsiflexion to neutral position and from neutral position to plantar flexion.

	Dorsiflexion to Neutral position (Deg)			Neutral position to plantar flexion (Deg)		
Subject	Bone	Skin	Skate	Bone	Skin	Skate
2	08.42	13.39	11.67	28.84	36.83	27.59
4	13.67	09.54	10.37	20.59	45.03	12.35
5	10.53	10.09	08.45	28.83	42.07	17.04
7	15.80	09.14	08.02	22.48	43.79	17.55
8	13.57	13.94	09.02	26.88	51.59	19.10
Mean	12.40 (2.91)	11.22 (2.27)	09.51 (1.50)	25.53 (3.79)	43.86 (5.33)	18.73 (5.56)

Table 2. Paired samples t-test values for Bone, skin, and skate vectors' rotations from dorsiflexion to neutral position.

	Dorsiflexion to neutral position			Neutral position to plantar flexion		
	Bone vs. skin (n = 5)	Skin vs. skate (n = 5)	Skate vs. bone (n = 5)	Bone vs. skin (n = 5)	Skin vs. skate (n = 5)	Skate vs. bone (n = 5)
P	0.59	0.14	0.18	0.01	0.00	0.02

When the total motion of the foot from dorsiflexion to plantar flexion was considered, the results (Table 3) showed a regular pattern of skate rotations being the smallest and skin rotations the largest for all subjects except subject 2 whose skate rotation in dorsiflexion was 3.3° higher than his bone rotation. Plantar flexion had a major influence on the total motion in that the mean skate rotations again underestimated mean bone rotation by 26% and mean skin rotation by 31%. This underestimation was significant for both bone-skate and bone-skin comparisons ($p<0.05$ in table 4). The results were systematic across subjects where skate rotations were about 70% of bone rotations (except for subject 2). As for the difference between skate rotation and skin rotation, it was also significant ($p<0.05$ in table 4) where mean skate rotation underestimated mean skin rotation by 49%.

Table 3. Bone, skin, and skate vectors' rotations from dorsiflexion to plantar flexion.

Subject	Bone	Skin	Skate
2	37.27	50.22	39.26
4	34.26	54.57	22.73
5	39.36	52.16	25.49
7	38.28	52.93	25.57
8	40.45	65.53	28.12
Mean	37.92 (2.37)	55.08 (6.04)	28.23 (6.45)

The results of this study show that skin rotations around the ankle joint significantly overestimate bone rotations by 31%. This overestimation corresponds to what is known about skin motion artefact in the literature. However, it appears to exist only during severe movements such as plantar flexion coupled with external rotation. The results of this study are interesting in relation to skate rotations underestimating bone rotations by 26%, and skin rotations by 49%. This underestimation did not exist during dorsiflexion. This finding is the opposite of what is known in the literature about shoe rotations in relation to bone and skin rotations (Reinschmidt, 1997). The difference between shoe and skate movement artefacts could be the result of the rigidity of the skate structure, which makes it far less flexible than the shoe.

Table 4. Paired samples t-test values for Bone, skin, and skate vectors' rotations from dorsiflexion to plantar flexion.

	Bone vs. skin (n = 5)	**Skin vs. skate (n = 5)**	**Skate vs. bone (n = 5)**
p	0.00	0.00	0.03

CONCLUSION: Based on the results of this study, it can be concluded that, unlike shoe motion, the rigidity of the skate structure causes the skate motion to underestimate the motion of the underlying bony and skin structures. However, it is not clear whether this difference exists in movements other than planatr/dorsiflexion around the ankle joint complex. Therefore, it is advised that results of kinematic studies of skating based on skate markers be interpreted with caution.

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