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Blood profiles in elite cross-country skiers: a 6-year follow-up

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Following the doping scandals at the World Championships in cross-country skiing in 2001, the International Ski Federation decided to generate individual blood profiles. From 2001 to 2007, 7081 blood samples from 1074 male and female elite cross-country skiers were collected and analyzed for hemoglobin concentration [Hb] and % reticulocytes (%rets). Data were applied to blood algorithms wherefrom blood model scores were calculated. From 1997–1999 to 2001–2002, the mean [Hb] was reduced by 0.9 g/dL to 15.3 g/dL in male skiers and by 0.4 g/dL to 13.8 in female skiers. From 2002–2003 to 2006–2007, the combination of increases in [Hb] and decreases in %rets led to pronounced increases in mean OFF-model scores. [Hb] was 0.2 g/dL higher at Olympic Games/World Championships (WOCs) than at World Cups competitions <4 weeks before and after WOCs. [Hb] and %rets increased with altitude in both genders. Since the introduction of an enlarged blood testing program, the mean [Hb] values were lowered to close to normal levels, but over the last 2–3 years there has been a small elevation and an increase in OFF-model scores, which may indicate a change in the manipulations used to elevate the [Hb].

In cross-country skiing, the advantage of having a high hemoglobin value ([Hb]) is illustrated by the fact that 50% of the medal winners at the World Cross-country Championships (WCCs) in Lahti in 2001 had a highly abnormal [Hb], whereas only 3% of the skiers placing between the 41st and 51st place had an abnormal [Hb] (Stray-Gundersen et al., 2003). High [Hb] values are rarely explained by genetic disorders but are more likely attained by medical interventions such as injections of recombinant human Erythropoietin (rhEPO) (Audran et al., 1999) or blood transfusions (Damsgaard et al., 2006). Blood sampling is an easy and cost-effective way to screen for various types of blood manipulation. In 1989, the International Ski Federation (FIS) introduced blood screening at the World Championships. Despite this, a steady increase in the mean [Hb] was observed in both male and female cross-country skiers from 1989 and until 1996 (Videman et al., 2000). The implementation of an upper [Hb] limit for men (18.5 g/dL) and women (16.5 g/dL) in 1997 led to a marked decrease in the number of highly abnormal [Hb] values, but the mean [Hb] in both genders were still higher than the population mean the following years (Videman et al., 2000). Furthermore, as a result of the doping scandals at the World Championships in Lahti 2001, an enlarged blood-testing program was initiated, combined with lowered [Hb] cut-offs (17.0 g/dL for men and 16.0 g/dL for women) and the introduction of % reticulocytes (%rets). Using absolute [Hb] cut-offs relates to the problem that [Hb] has a low intra- to inter-individual variability ratio and therefore skiers with a natural high [Hb] may be excluded, while skiers with natural low [Hb] can increase their [Hb] close to the limit without being excluded. Therefore, a blood-based algorithm (OFF z-score) that only allows fluctuations within an individuals physiological range has been developed (Sharpe et al., 2006). If the score exceeds a predefined cut-off, the skier has with great certainty been using rhEPO before the sample collection. This algorithm is based on the OFF model, which combines the [Hb] and %rets into a number with a high prognostic value for using rhEPO (Parisotto et al., 2001).

The main objective of this study is to evaluate the initiative in 2001 by FIS with regard to its effect on world-class cross-country skiers [Hb] and %rets data and subject their individual and mean data to specific blood analyses algorithms. Another objective was to examine the effect of low to median altitude on these blood variables as well as variations related to major championships.

Methods

As part of FIS's anti-doping testing procedure, 3961 venous blood samples from 440 female and 3120 samples from 634 male cross-country skiers were obtained from November 2001 to July 2007. The license to compete in one of FIS's events includes acceptance of blood testing.

Authorized medical personnel performed blood collection. Samples were categorized as "out of competition (OOC)," "full field," "pre-starter," "post competition," "national testing" or "follow-up". OOC testing was performed on skiers not participating in any competition at the time of sampling. Owing to standardization of the blood sampling procedure and analysis, results from only "out of competition," "full field" and "pre-starter" were included in this study.

Samples were taken as non-fasting samples with subjects seated for 10 min before venous puncture. Tourniquet time was <30 s before blood was drawn into ethylenediaminetetraacetic acid-covered tubes and analyzed for [Hb] and %rets within 8 h. [Hb] were analyzed on a Sysmex KX 21 (Sysmex, Norderstedt, Germany), while %rets were analyzed on a Sysmex R-500 (Sysmex). The majority of samples were analyzed immediately after collection. Instruments were calibrated before analysis. On full testing days, the hematological analyzers were quality controlled three times during the day with high, normal and low standards provided by the manufacturer.

Calculations

[Hb] coefficient of variation (CV) was calculated as

$$[\mathrm{Hb}]_{\mathrm{CV}} = [\mathrm{Hb}]_{\mathrm{SD}} \times 100/[\mathrm{Hb}]_{\mathrm{Mean}}.$$

To translate [Hb] to hematocrit, multiply [Hb] by approximately 2.98.

To translate [Hb] in g/dL to mmol/L, divide by 1.6125.

The OFF-model score was calculated as (Parisotto et al., 2003)

$$\text{OFF-model score} = [\mathrm{Hb}] - 60 \times \sqrt{\%\mathrm{rets}},$$

where [Hb] is in g/L.

OFF-model cut-off scores for false positives (Gore et al., 2003):

	Males	*Females*
1 in 10 false positives:	≥ 104.6	≥ 92.2
1 in 100 false positives:	≥ 116.7	≥ 104.4
1 in 1000 false positives:	≥ 125.6	≥ 113.5

Hb *z*-score was calculated as (Sharpe et al., 2006)

$$\mathrm{Hb}\,z\text{-score} = (\mathrm{Hb}_{\mathrm{current}} - \mathrm{Hb}_{\mathrm{mean}}) \Big/ \sqrt{(\sigma^2(1+1/n))},$$

where $\mathrm{Hb}_{\mathrm{current}}$ is the [Hb] of the current sample, $\mathrm{Hb}_{\mathrm{mean}}$ is the mean [Hb] score of all samples taken before the current sample, σ^2 the variance between readings from the individual and n the number of samples taken before the current sample.

OFF *z*-score was calculated as (Sharpe et al., 2006)

$$\mathrm{OFF}\,z\text{-score} = (\mathrm{OFF}_{\mathrm{current}} - \mathrm{OFF}_{\mathrm{mean}}) / \sqrt{(\sigma^2(1+1/n))},$$

where $\mathrm{OFF}_{\mathrm{current}}$ is the OFF-model score of the current sample, $\mathrm{OFF}_{\mathrm{mean}}$ the mean OFF-model score of all samples taken before the current sample, σ^2 the variance between readings from the individual, and n the number of samples taken before the current sample.

Cut-off scores for Hb *z*-score and OFF *z*-score (Sharpe et al., 2006):

	Males	*Females*
1 in 50 false positives (suspicious)	≥ 2.33	≥ 2.33
1 in 1000 false positives (no start)	≥ 3.09	≥ 3.09

Statistics

Data are represented as means ± SEM. Differences between seasons and between altitudes were identified with an unpaired *t*-test. Differences between Olympic Games/World Championships (WOCs) and World Cups (WCs) were identified with a Wilcoxon Signed Rank Test. Differences between Olympic Game (OG) in Pragelato and WCs before and after were identified with a paired *t*-test. Significance level was set at $P<0.05$.

Results

Blood parameters

Seasonal data are presented in Figs 1 and 2. From the late 1990s to 2001–2002, the mean [Hb] decreased by 0.9–15.3 g/dL in males and by 0.4–13.8 g/dL in females. Seasonal variations in [Hb] ranged from 14.8 to 15.7 g/dL in males and from 13.4 to 14.2 g/dL in females during the testing period. The corresponding values for %rets were 0.8–1.3% and 0.9–1.3%. There was a decrease in [Hb] from 2001–2002 to 2002–2003 of 0.5–14.8 g/dL in males ($P<0.001$) and from 0.4–13.4 g/dL in females ($P<0.001$), followed by an increase during the subsequent seasons. From 2001–2002 to 2006–2007, we found a decrease in %rets of 0.5 percent point decreasing to 0.8% in males ($P<0.001$) and of 0.4 percent point decreasing to 0.9% in females ($P<0.001$). This inverse change in [Hb] and %rets led to increases in mean OFF-model scores of 13.6 points in males and 12.9 points in females ($P<0.001$) from 2002–2003 to 2006–2007 ($P<0.001$) (Table 1). In both genders, [Hb] was the highest during seasons with OG (2001–2002 and 2005–2006) (Figs 1 and 2).

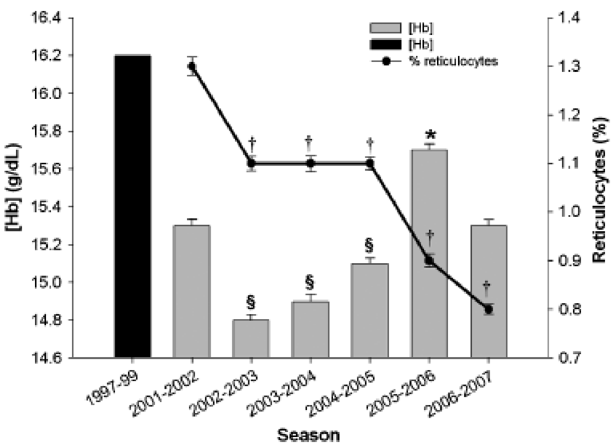

Fig. 1. Mean+SEM [Hb] (bars) and %rets ± SEM (line) in male skiers from 2001/2002 to 2006/2007. Data are presented as means of each season. The left *y*-axis represents [Hb] and the right *y*-axis represents %rets. The *x*-Axis represents season. The black bar represents the mean [Hb] from 1997 to 1999 (4), while each gray bar represents one season. [Hb], hemoglobin concentration; %rets, percentage of reticulocytes. *[Hb] significantly higher than 2001–2002 ($P<0.05$). § [Hb] significantly lower than 2001–2002 ($P<0.05$). †%rets significantly lower than 2001–2002 ($P<0.05$).

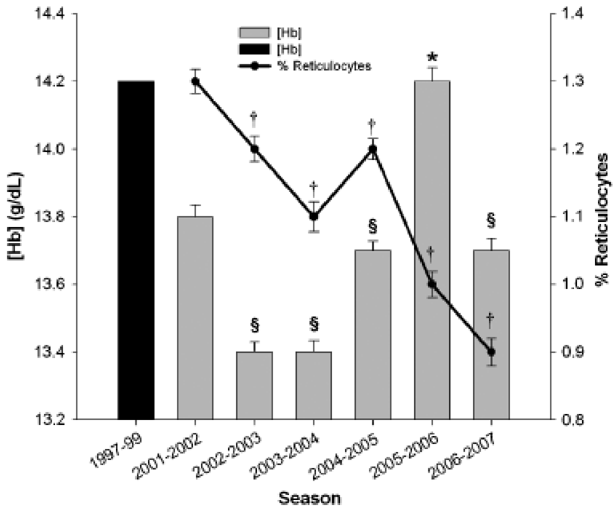

Fig. 2. Mean+SEM [Hb] (bars) and %rets ± SEM (line) in female skiers from 2001/2002 to 2006/2007. Data are presented as means of each season. The left *y*-axis represents [Hb] and the right y-axis represents %rets. The *x*-Axis represents season. The black bar represents the mean [Hb] from 1997 to 1999 while each gray bar represents one season (4). [Hb], hemoglobin concentration; %rets, percentage of reticulocytes. *[Hb] significantly higher than 2001–2002 ($P<0.05$). §[Hb] significantly lower than 2001–2002 ($P<0.05$). †%rets significantly lower than 2001–2002 ($P<0.05$).

In Fig. 3, a blood profile of a skier who was tested positive for Darbepoetin is illustrated. [Hb] ranged from 15.4 to 17.9 and %rets from 0.5 to 2.1. The successive blood profile showed increases in %rets before increases in [Hb]. The skier had an OFF-score of 127, a Hb *z*-score of 2.4 and an OFF *z*-score of 3.13.

Cut-offs

In 2001–2002, 52 males and 55 females exceeded the %rets cut-off of 2.0%. This number was markedly higher than during the other seasons (Table 2). The number of male skiers exceeding the [Hb] cut-offs was by far the highest in 2005–2006 (33 males), while during all six seasons only 17 female skiers exceeded the 16 g/dL cut-off. The mean intraindividual [Hb] CV ranged from 3.48 to 4.04 in males and from 3.76 to 4.45 in females during the period (Table 1). The largest intraindividual CVs in [Hb] were 8.0 and 10.0 for males and females, respectively.

Effect of altitude

In male skiers, %rets was 0.13 percent point ($P<0.001$) and [Hb] 0.05 g/dL higher in samples collected at 600–1200 meters above sea level (m.a.s.l.) compared with samples collected below 600 m.a.s.l. and 0.09 percent point ($P<0.001$) and 0.05 g/dL higher in samples collected above 1200 m.a.s.l. compared with samples collected at 600–1200 m.a.s.l. (Fig. 4). In female skiers, %rets was 0.08 percent point ($P<0.001$) and [Hb] 0.1 g/dL ($P<0.001$) higher in samples collected at 600–1200 m.a.s.l. compared with samples collected below 600 m.a.s.l. and 0.1 percent point ($P<0.05$) and 0.05 g/dL ($P<0.05$) higher in samples collected above 1200 m.a.s.l. compared with samples collected at 600–1200 m.a.s.l. (Fig. 5).

WOCs vs. WC

In male skiers, [Hb] was higher in subjects during WOCs than at WCs taking place <4 weeks before ($P<0.05$) and after WOCs ($P<0.001$) (Figs 6 and 7). Female skiers had higher [Hb] during WOCs than at WCs after WOCs ($P<0.001$). During the OG in Pragelato in 2006, [Hb] were on average 0.5 higher ($P<0.05$) in males and 1.0 g/dL higher ($P<0.05$) in females than at a WC in Davos 1 week before and 1.3 g/dL ($P<0.001$) and 1.1 g/dL higher ($P<0.001$) in male and female skiers, respectively, than at a WC in Sapporo 1 month later (Figs 8 and 9). Furthermore, [Hb] were 1.2 g/dL ($P<0.001$) higher in both genders at the OG in Pragelato than at a WC in Pragelato in 2005.

Discussion

We found the mean [Hb] for male and female skiers from 2001 to 2007 to be markedly lower than the corresponding values during the late 1990s but still higher than the population mean. Initially, there was a large decrease in [Hb] reaching close to normal population mean values, followed by an increase during the next five seasons. In this latter period, we found a decrease in %rets, which, in combination with an increase in [Hb], resulted in a concomitant increase in the mean OFF-model score. This might indicate a change in blood-doping practices among some of the skiers.

Major changes in mean [Hb] and %rets in a large cohort of skiers over time are surprising, in a situation where the population of skiers submitted to health controls did not change and where no changes in technology used to perform the analyses or the pre-analytical standardization took place. Furthermore, high mean [Hb] values in endurance-trained skiers are unexpected from a physiological point of view because endurance training induces relatively larger increases in the plasma volume than in the red cell volume, which leads to a decrease in [Hb] (Schmidt et al., 2000). In a warmer environment, this expansion of the plasma volume and lowering of the [Hb] is more pronounced (Harrison, 1985). It can be speculated whether cross-country skiers [training

Table 1. Mean, maximum (max) and minimum (min) of OFF-model score (OFF-score), [Hb] coefficient of variation ([Hb] CV), hemogloin z-score (hb z-score) and OFF z-score (OFF model z-score) for each season for males and females are presented

Males					Females				
2001–2002 ($n=617$)	OFF-score	[Hb] CV	Hb *z*-score	OFF *z*-score	2001–2002 ($n=648$)	OFF- score	[Hb] CV	Hb *z*-score	OFF *z*-score
Mean	85.4	3.98	0.46	0.12	Mean	69.4	4.45	0.47	0.18
Max	127.1	7.2	2.9	4.3	Max	131.5	9.2	3.8	3.9
Min	32.8	1.0	− 2.9	− 5.7	Min	16.2	1.5	− 2.4	− 3.0
2002–2003 ($n=721$)					2002–2003 ($n=577$)				
Mean	84.9	4.04	− 0.31*	0.04	Mean	66.7*	4.24	− 0.35*	− 0.08*
Max	131.1	7.8	2.5	3.8	Max	114.6	8.0	2.4	3.5
Min	50.4	1.0	− 3.2	− 3.4	Min	23.3	1.4	− 3.1	− 3.0
2003–2004 ($n=454$)					2003–2004 ($n=354$)				
Mean	89.8†	3.81	− 0.12*	0.30	Mean	71.2	3.76*	− 0.26*	0.16
Max	135.2	8.0	3.2	3.1	Max	108.1	7.8	4.2	2.7
Min	54.3	1.1	− 2.4	− 2.6	Min	34.0	1.5	− 3.1	− 2.1
2004–2005 ($n=835$)					2004–2005 ($n=649$)				
Mean	88.9†	3.48*	0.16*	0.08	Mean	73.6†	3.79*	0.13*	0.26
Max	127.1	7.8	3.4	2.9	Max	112.1	7.7	2.8	4.3
Min	44.0	0.8	− 2.5	− 3.0	Min	24.1	1.5	− 2.4	− 3.6
2005–2006 ($n=598$)					2005–2006 ($n=397$)				
Mean	99.9†	3.82	0.89†	0.97†	Mean	83.8†	4.09	0.88†	0.90†
Max	146.1	7.5	3.2	4.8	Max	114.8	7.5	3.4	3.6
Min	57.0	1.2	− 2.1	− 2.0	Min	43.6	0.9	− 1.4	− 1.3
2006–2007 ($n=736$)					2006–2007 ($n=495$)				
Mean	98.5†	3.93	0.08	0.49†	Mean	79.6†	4.18	− 0.08*	0.43†
Max	137.0	7.8	3.0	3.9	Max	122.1	10.0	3.5	3.6
Min	64.0	1.3	− 3.3	− 2.7	Min	10.9	0.4	− 4.1	− 2.9

N, number of subjects.
*Lower than 2001–02 ($P<0.05$).
†Higher than 2001–02 ($P<0.05$).

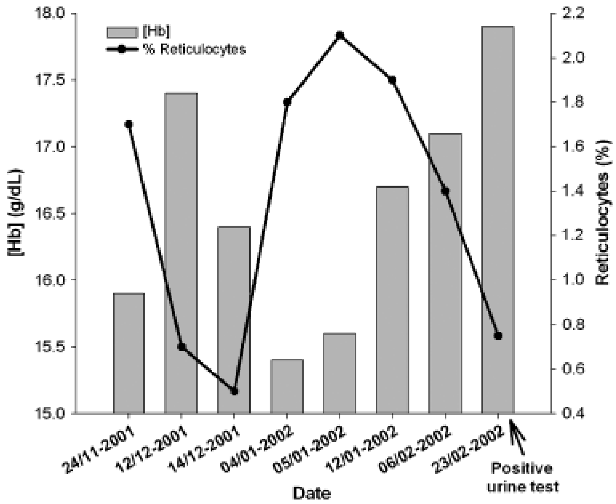

Fig. 3. Change in [Hb] (bars) and %rets (line) during a 3-month period from a skier who tested positive for Darbepoetin. The left *y*-axis represents [Hb] and the right *y*-axis represents %rets. The *x*-Axis represents time. [Hb], hemoglobin concentration; %rets, percentage of reticulocytes.

and competing often at sub-zero degrees (C°)] experience less of this plasma volume expansion and therefore may maintain a more normal [Hb]. Nevertheless, a higher [Hb] than the population mean [Hb] is difficult to anticipate in such a large cohort of cross-country skiers, although the cohort being predisposed for an elevated [Hb] could be the reason for this population becoming elite endurance athletes. In relation, small plasma volume shifts would result in low CVs in concentration-derived parameters as i.e. the [Hb]. The CVs in both male and female skiers of approximately 4% are higher than the median CV of 2.9% reported in a cohort of 923 male football players (Malcovati et al., 2003). Whether this is the result of differences in sports-related physiological demands or the use of blood manipulations cannot be determined from our data.

The observed decrease in [Hb] from the 1990s to the 2001–2002 season is likely to be explained by the announcement of a strengthened anti-doping program by FIS. The observed reduction could be due to the fact that three skiers were tested positive for exogenous EPO or Darbepoetin. It is also of note that there was a marked decrease in %rets and in the number of subjects having high %rets (>2.0) after the Olympic season 2001–2002. In 2001–2002, 52 male and 55 female skiers had >2%rets, while only 10 males and 19 females exceeded this limit during 2005–2006 and 2006–2007. This inverse relationship between [Hb] and %rets has not been ascribed to any pathological abnormality and therefore forms the basis for the OFF model (Parisotto et al., 2001). An elevated [Hb] exists in tandem with a suppressed %rets after blood transfusions (Damsgaard et al., 2006) and for weeks after the end of rhEPO administration (Audran et al., 1999). The OFF model therefore expands the short window of possible detecting signs of exogenous EPO in a urine test. A male person with normal [Hb] (14.3 g/dL) and %rets (1.1%) has an OFF-model score of 80.1. In 2002/2003, male skiers had OFF-model scores of 84.9, which is close to the population mean. During the following seasons, the mean OFF-model score increased, reaching a peak level of 99.9 in 2005/2006, thereby approaching a value of 104.6, which is statistically found in 1 out of 10 athletes, who has not been using "forbidden substances". In female skiers, OFF-model scores increased from 66.7 in 2002/2003 to 83.8 in 2005/2006. For women the 1 in 10 cut-off value is 92.2. Interestingly, a pronounced increase in OFF-model scores during the same period is in accordance with values presented by the International Cycling Federation (UCI) in 2005 (Zorzoli, 2005). Therefore, this indicates that a change has occurred since 2001–2002 in the way an undefined number of not only cross-country skiers but also cyclists have used blood doping. A likely explanation is that the use of the more potent form of rhEPO, Darbepoetin, has decreased. Darbepoetin is detectable for a longer period in the urine than rhEPO because of a higher potency and is therefore more difficult to administer (Morkeberg et al., 2007). The high number of high %rets (>2%) during the 2001–2002 season (Table 2) might be explained by Darbepoetin abuse that season. A change in the type of blood-boosting substances used and the way it is administered, in combination with an increased use of blood transfusions during the following period in a subpopulation of the athletes, are likely explanations for the observed increase in [Hb] and decrease in %rets from 2003 to 2004 and onwards.

The blood profile from a skier who was tested positive for Darbepoetin is presented in Fig. 3. The variations in both [Hb] and %rets during the 3-month sampling period are typical of bone marrow stimulation caused by rhEPO/Darbepoetin abuse. It shows a marked increase in %rets before an increase in [Hb], followed by a decrease in %rets when Darbepoetin administration has ceased, and the [Hb] has reached a high level. The variation can be numerically determined by the *z*-score. Variations in [Hb] are expressed as an Hb *z*-score while the combined variations in [Hb] and %rets are expressed as an OFF *z*-score. The presented skier had an OFF score of 127, a Hb *z*-score of 2.4 and an OFF z-score of 3.13 at the time of the positive urine test. Only 1 in 1000 clean athletes exceeds an OFF score of 125.6 or a score of 3.09 in Hb *z*-score or OFF *z*-score (Sharpe et al., 2006). Introducing individual blood-based

Table 2. Males and females exceeding various cut-offs each season

Males	No. of tests ≥ 600 m.a.s.l.	[Hb] ≥ 17 g/dL	% rets ≥ 2.0	% rets ≤ 0.3	OFF-score ≥ 104.6	OFF-score ≥ 116.7	OFF-score ≥ 125.6	Hb *z*-score ≥ 2.33	Hb *z*-score ≥ 3.09	OFF *z*-score ≥ 2.33	OFF *z*-score ≥ 3.09	[Hb] CV ≥ 10%
2001–2002	416	10	52	0	56	9	2	5	0	11	1	4
2002–2003	402	1	22	1	53	10	1	1	0	10	3	0
2003–2004	352	1	2	3	41	6	2	2	1	8	0	0
2004–2005	625	9	13	0	88	11	1	6	1	7	0	1
2005–2006	534	33	8	1	235	48	10	21	1	27	5	2
2006–2007	160	17	2	2	236	44	9	9	0	14	5	2
Females	**No. of tests ≥ 600 m.a.s.l.**	**[Hb] ≥ 16 g/dL**	**%rets C 2.0**	**%rets ≤ 0.3**	**OFF-score ≥ 92.2**	**OFF-score ≥ 104.4**	**OFF-score ≥ 113.5**	**Hb *z*-score ≥ 2.33**	**Hb *z*-score ≥ 3.09**	**OFF *z*-score ≥ 2.33**	**OFF *z*-score ≥ 3.09**	**[Hb] CV ≥ 10%**
2001–2002	478	1	55	0	30	8	1	14	2	15	3	5
2002–2003	307	9	36	0	28	4	1	2	0	12	3	0
2003–2004	259	1	15	0	13	1	0	3	1	6	0	0
2004–2005	449	0	25	1	28	4	0	1	0	5	1	1
2005–2006	338	2	7	0	110	14	2	19	3	15	3	0
2006–2007	194	4	12	2	68	11	1	6	2	8	3	2

No. of tests ≥ 600 m.a.s.l., Number of tests taken at locations above 600 meters above sea level; [Hb], hemoglobin concentration; %rets, percentage of reticulocytes; OFF-score, OFF model score; CV, coefficient of variation; hb *z*-score, hemoglobin *z*-score; OFF *z*-score, OFF model *z*-score for each season for males and females. *N*, number of subjects.

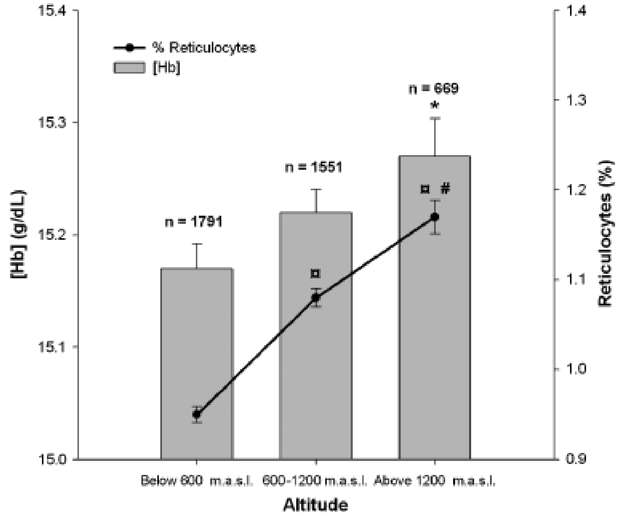

Fig. 4. Mean+SEM [Hb] (bars) and %rets ± SEM (line) in male skiers with regard to altitude at the place of competition. Altitude at the place of competition was divided into three categories in respect to meters above sea level (m.a.s.l.): below 600, 600–1200 and above 1200. The left *y*-axis represents [Hb] and the right *y*-axis represents %rets. The *X*-Axis represents altitude. [Hb], hemoglobin concentration; %rets, percentage of reticulocytes. *N*, number of subjects. *[Hb] significantly higher than below 600 m.a.s.l. ($P<0.05$). ¤%rets significantly higher than below 600 m.a.s.l. ($P<0.05$). #% rets significantly higher than 600–1200 m.a.s.l. ($P<0.05$).

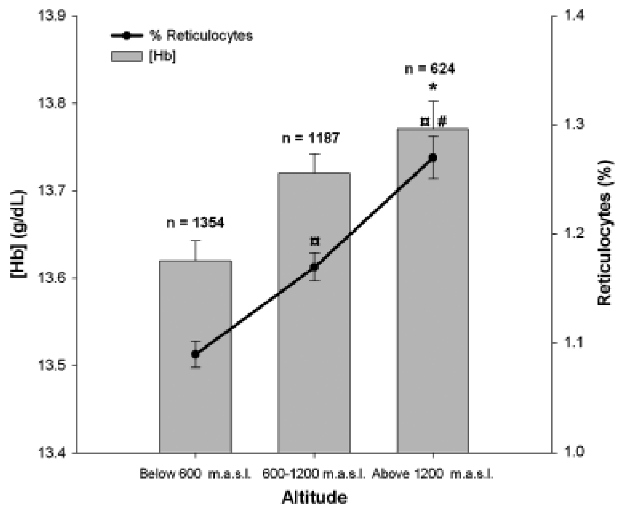

Fig. 5. Mean+SEM [Hb] (bars) and %rets ± SEM (line) in female skiers in regard to altitude at the place of competition. Altitude at the place of competition was divided into three categories in respect to meters above sea level (m.a.s.l.): below 600, 600–1200 and above 1200. The left *y*-axis represents [Hb] and the right y-axis represents %rets. The *x*-Axis represents altitude. [Hb], hemoglobin concentration; %rets, percentage of reticulocytes. *N*, number of subjects. *[Hb] significantly higher than below 600 m.a.s.l. ($P<0.05$). ¤%rets significantly higher than below 600 m.a.s.l. ($P<0.05$). #%rets significantly higher than 600–1200 m.a.s.l. ($P<0.05$).

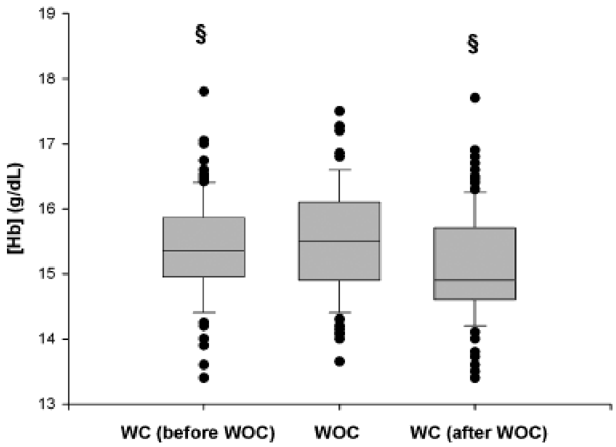

Fig. 6. [Hb] of male skiers participating in both the Olympic Games/World Championships (WOCs) and World Cups (WCs) <4 weeks before and after the WOC. The ends of the boxes define the 25th and 75th percentiles, with a line at the median and error bars defining the 10th and 90th percentiles. Data points beyond the 10th and 90th percentiles are displayed as black dots. The *y*-Axis represents [Hb] and the *x*-axis represents event. Number of subjects = 119; [Hb], hemoglobin concentration. *[Hb] significantly lower than WOC ($P<0.05$).

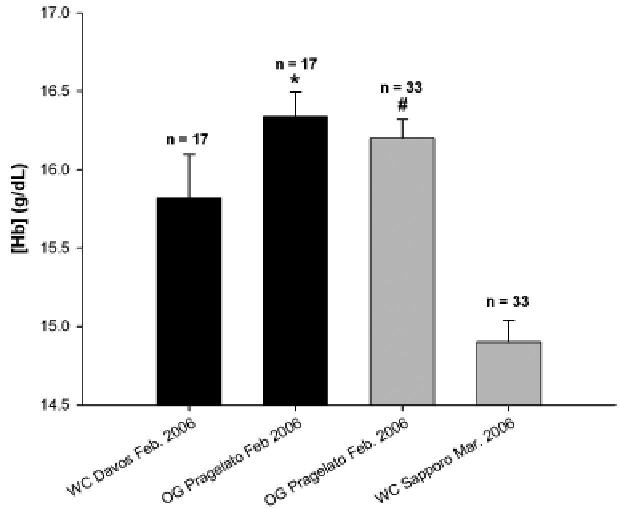

Fig. 8. [Hb]+SEM of male skiers participating in the Olympic Game (OG) in Pragelato 2006 and a World Cup (WC) in Davos 1 week before the OG or a WC in Sapporo 1 month after the OG. Black bars represent the [Hb] in male skiers participating in the OG and in the WC in Davos ($n = 17$), while gray bars represent the [Hb] in male skiers participating in the OG and in the WC in Sapporo ($n = 33$). The *y*-Axis represents [Hb] and the *x*-axis represents event. *N*, number of subjects. [Hb], hemoglobin concentration. *Significantly higher in Pragelato than in Davos ($P<0.05$). #Significantly higher in Pragelato than in Sapporo ($P<0.05$).

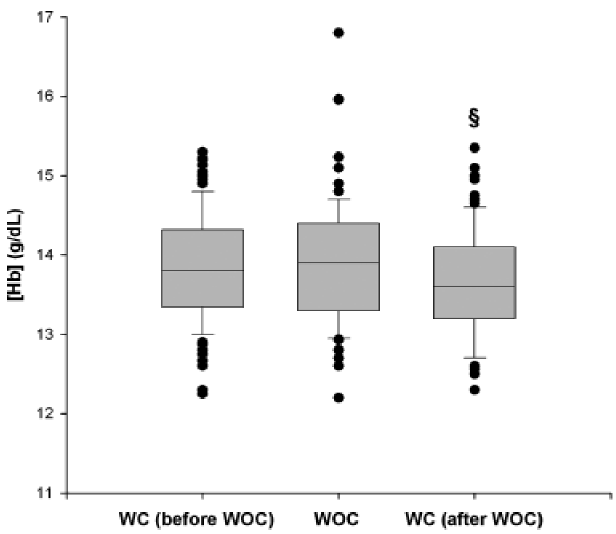

Fig. 7. [Hb] of female skiers participating in both the Olympic Games/World Championships (WOCs) and World Cups (WCs) <4 weeks before and after the WOC. The ends of the boxes define the 25th and 75th percentiles, with a line at the median and error bars defining the 10th and 90th percentiles. Data points beyond the 10th and 90th percentiles are displayed as black dots. The *y*-Axis represents [Hb] and the *x*-axis represents event. Number of subjects = 109; [Hb], hemoglobin concentration. *[Hb] significantly lower than WOC ($P<0.05$).

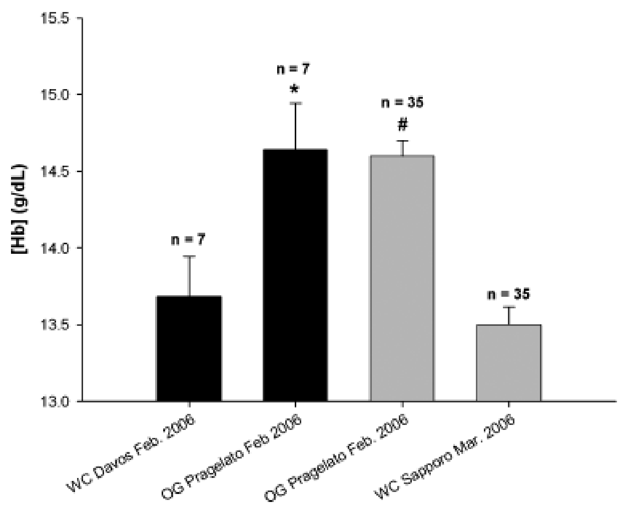

Fig. 9. [Hb]+SEM of female skiers participating in the Olympic Game (OG) in Pragelato 2006 and a World Cup (WC) in Davos 1 week before the OG or a WC in Sapporo 1 month after the OG. Black bars represent the [Hb] in female skiers participating in the OG and in the WC in Davos ($n = 7$), while gray bars represent the [Hb] in female skiers participating in the OG and in the WC in Sapporo ($n = 35$). The *y*-Axis represents [Hb] and the *x*-axis represents event. *N*, number of subjects. [Hb], hemoglobin concentration. *Significantly higher in Pragelato than in Davos ($P<0.05$). #Significantly higher in Pragelato than in Sapporo ($P<0.05$).

algorithms therefore seems to be effective in the targeting of cheating athletes.

Another finding was that [Hb] in both female and male skiers were higher during WOCs than during WC competitions held less than 4 weeks before or after the event. The largest difference was seen between WOCs and WCs taking place after the

WOCs. Skiers are expected to have low [Hb] due to peak fitness levels at major competitions compared with the rest of the season (Schmidt et al., 2000). Conversely, boosting red cell mass before an important competition only lasts a couple of weeks when the treatment is stopped and is followed by a decrease in [Hb] 1–3 weeks (depending on the type of manipulation) after the event (Audran et al., 1999; Damsgaard et al., 2006). [Hb] values during the 2006 OG in Pragelato were on average 1.1–1.3 g/dL higher than [Hb] from the same cohort obtained during a WC in Sapporo 1 month later. Although Pragelato is located at 1500 m.a.s.l. and Sapporo located at 150 m.a.s.l., our data suggest that only 0.1–0.15 g/dL of this difference can be explained by the effect of altitude (Figs 4 and 5). Furthermore, skiers participating both in the OG in Pragelato in 2006 and in a WC in Pragelato in 2005 had 1.2 g/dL higher [Hb] at the OG than at the WC. This finding excludes a possible altitude effect as a reason for the high [Hb] at the OG in Pragelato 2006 (15.9 g/dL for males and 14.6 g/dL for females), which is supported by lower [Hb] (0.5 g/dL in males and 1.0 g/dL in females) at a WC in Davos (1500 m.a.s.l.) only 1 week before the OG. With this in mind, changes in [Hb] caused by the use of altitude simulators i.e. hypoxic chambers cannot be excluded.

Perspectives

Intensifying the blood-testing program in 2001 by FIS seems to have had an effect reflected by the observed lower mean [Hb] values compared with the 1990s. Bearing this in mind, [Hb] are still higher than expected and the increases in OFF-model scores may indicate a change in the doping substances used and the way they are used by an undefined part of elite cross-country skiers.

Key words: hemoglobin, fitness performance, blood doping, blood algorithms.

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