Original Article

Review of World Rugby's Test Method 01 head injury criteria: Procedure analysis and optimisation

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Abstract

Rugby is a close-contact sport in which players occasionally fall headfirst to the ground during scrums and tackles. Because head impacts represent an obvious threat to players' integrity and safety, World Rugby, Rugby's International Governing Body, developed a test method named Test Method 01 to evaluate the capacity of the playing surface to mitigate head impacts by determining the critical fall height (CFH). The aim of this study is to analyse World Rugby's current Test Method 01 head injury criteria (HIC), which consider a field as unsafe if the CFH is below 1.3 m. To make this analysis, a pilot study was performed on seven artificial turf rugby fields. At each field, a three-drop procedure was performed to estimate the initial CFH (CFH_0). Subsequently, the procedure was repeated on each surface at 50-mm intervals, from 0.6 m below to 0.6 m above CFH_0. All possible combinations of four height–HIC data pairs with two height values below and above 1000 HIC were obtained. A comparison was performed between the linear adjustment, currently prescribed in Test Method 01 to calculate the CFH_0, and the quadratic adjustment. In particular, the percentage of outliers obtained when applying both the linear and quadratic adjustment and the robustness of the regressions were investigated. The results show that the current Test Method 01 can be improved by applying two main modifications: first, replacing the linear adjustment with a quadratic adjustment, and second, adapting the current test restrictions by maintaining the maximum difference between the highest and the lowest drop heights in 1.00 m, increasing the minimum difference between consecutive drop heights from 0.15 to 0.20 m and removing the current prohibition on obtaining HIC values close to 1000.

Keywords

Standard, artificial turf, sport surfaces, reliability, dispersion, head impact, world rugby

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Introduction

Mechanical properties of sport surfaces, understood as those parameters describing the dynamic behaviour of the surface system,[1] are significant to athlete performance and safety because they have the potential to affect their biomechanical, physical and physiological responses during play.[2–7] These mechanical properties are generally evaluated through mechanical devices and test methods in which athletes' contact with the ground is somehow reproduced.[8] Thus, it is recognised by most of the international standards and sports federations for the assessment and regulation of sports surfaces.[9]

Rugby is a close-contact sport in which players occasionally fall headfirst to the ground during various events of the game, such as scrums and tackles.[10] Because impacts suffered to the head represent an obvious threat to players' integrity and safety, Rugby's World Governing Body, World Rugby, developed the Test Method 01 head injury criteria (HIC) to evaluate the capacity of the playing surface to mitigate head

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Table 1. Restrictions required by World Rugby's test method 01 head injury criteria.

N	Restriction
(i)	There is a maximum difference between the highest and the lowest drop heights (1.00 m)
(ii)	There is a minimum difference between consecutive drop heights (0.15 m)
(iii)	There can be no HIC values contained in a range around 1000 (975–1025)

impacts[11] by determining the critical fall height (CFH). The CFH is the maximum free fall height for which a surface provides an adequate level of impact attenuation. The CFH is defined as the height at which the HIC equals 1000 and whose test method is widely described in the determination of the CFH using the HIC (World Rugby Test Method 01).[11]

It is important to note that HIC is a measure of the likelihood of head injury arising from an impact. Therefore, CFH must be estimated by the assessment of the HIC of the surface. World Rugby considers that a field is unsafe if the CFH is below 1.3 m. In general terms, the test consists of letting a 4.6-kg head form fall freely to the ground (drop test) from different heights and recording the magnitude of each impact in HIC units. The HIC is obtained by an accelerometer with the following formula[11]:

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

Where t_1 and t_2 are the initial and final times (in s) of the interval during which HIC attains maximum value, and acceleration a is measured in terms of g.

The method stipulates that three-drops must be made in the same spot, extracting the result of the highest HIC (30 ± 5 s between drop), repeating from four different heights (different spot for each height, spaced at least 200 mm). The highest HIC values for each height, together with their corresponding heights, are used to estimate a linear regression. This linear regression is used to calculate the height at which the HIC equals 1000.

Besides having two HIC values below 1000 and two above, the four height–HIC data pairs must also meet the restrictions (currently required values in parentheses) included in Table 1, initially defined to try to improve the goodness of fit for the regression:

A representation of the test method and the restrictions above are shown in Figure 1. Furthermore, Figure 2 provides an example of the distribution of normal four height–HIC data pairs.

In practice, technicians accredited to carry out this test can select the test heights following different and varied approaches, obtaining a wide range of HIC values. This result means that the sample of points used to make the regression for the same surface will be different from one technician to another; therefore, different CFH results could be obtained. Due to this dispersion in the results, there will always be a certain percentage of outliers; that is, there will always be certain technicians whose diagnosis could be inaccurate or far from normal (a fact that has been suggested by World Rugby after the latest inter-laboratory comparisons). This possible problem also adds importance in reviewing other methods for quality control of artificial turf.[12]

Due to the importance of this test to support player head-impact safety, this study aims to review the current test method to determine whether it can be improved and simplified through better organisation and adjustment of the regression calculation (i.e. improving the use of data and the restrictions applied, without any change in the equipment). We consider that the method is improved if its repeatability increases, that is, if the percentage of outliers (%out) obtained during multiple tests decreases.

Methods

A pilot study was performed on seven artificial homologated turf rugby fields. In each of them, a complete three-drop procedure was performed to obtain a first estimate of the CFH (CFH_0). Then, the procedure was repeated on each surface at 50-mm intervals, from 0.6 m below to 0.6 m above CFH_0, obtaining 25 heights. All possible combinations of four height–HIC data pairs with two HIC values below and above 1000 were obtained, with no other restriction applied at this stage. Initially, 5148 observations were obtained for each surface.

First, the comparison between the linear adjustment (currently prescribed in the test method) and the quadratic adjustment was investigated (due to the nature of the distribution of the points in the regression, as seen in Figure 2). The %out were calculated after estimating the CFH with both the linear adjustment and the quadratic adjustment with the actual method restrictions. It is considered that a value is an outlier if it is outside the confidence interval setting, with the confidence level at 95%.

Once the most appropriate type of adjustment was clarified, the %out obtained when applying the different restrictions to the test method was investigated. The %out obtained when gradually applying restrictions (see Table 1) was investigated, individually and combined.

Finally, once the most effective combination of restrictions to reduce the %out was found, we investigated the results in case of eliminating the third of the

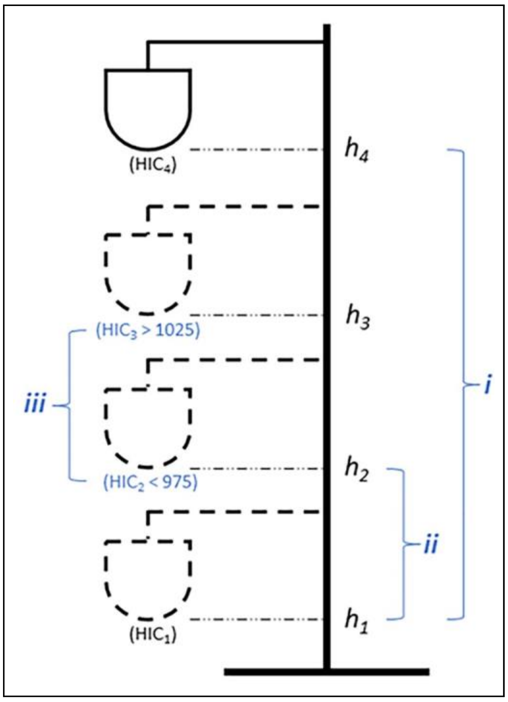

Figure 1. Representation of the different restrictions imposed in the current test method, in blue.
hi: test height; HIC: head injury criteria, which express the magnitude of the impact from each test height.

three-drop tests required in a certain test point, with the aim of considerably simplifying the test method. To do so, the results obtained were compared with the three-drop method with those of the two-drop method by carrying out two different analyses: first, the %out was calculated as it was done previously; second, the agreement between HIC values obtained with the three-drop and the two-drop methods was analysed by the mean bias, the random error (standard deviation of the bias), the lower limit of agreement and upper limit of agreement (calculated as $\pm$1.96 times the standard deviation of the mean bias [95%LOA– ‑), the product-moment correlation (r) and the intraclass correlation coefficients (ICCs). r was evaluated as trivial ($<$0.10), small (0.10–0.30), moderate (0.30–0.50), large (0.50–0.70), very large (0.70–0.90) or nearly perfect (0.90–1.00).[13] ICC values demonstrated low (ICC $<$ 0.4), moderate (0.4 $\leq$ ICC $<$ 0.75) and excellent (ICC $\geq$ 0.75) inter-method reliability.[14] Furthermore, Bland–Altman charts were developed with this information to evaluate the direction of the bias. The statistical analysis was carried out using IBM SPSS Statistics software,[15] and Bland–Altman plots were also obtained using Stata software.[16] The significance level was set at $p < 0.05$.

Results

Linear versus quadratic adjustment

Table 2 shows the number of outliers obtained when using the linear and the quadratic adjustments with the

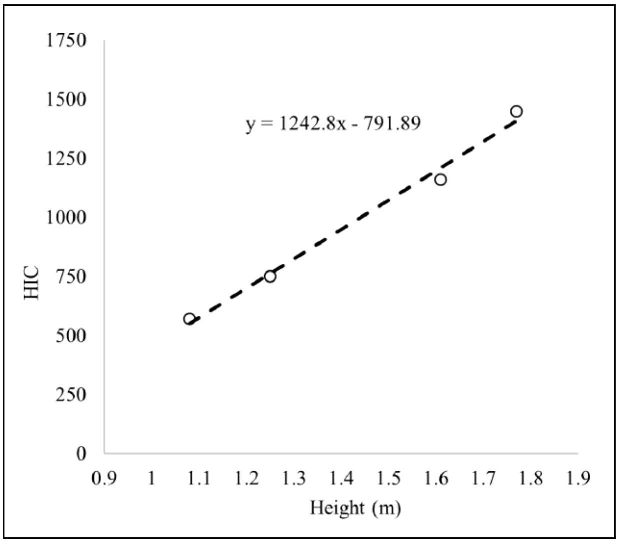

Figure 2. Distribution of a normal four height–HIC data pairs.

current method and restrictions. Because the initial number of combinations (n) is the same for the linear and quadratic in each field, the reduction in the number of outliers indicated in Table 2 from 80 in linear to 23 cases in quadratic reflects that the quadratic is the most appropriate adjustment.

Furthermore, Figure 3 shows the linear and quadratic adjustments from two random observations included in Table 2, as an example. The quadratic adjustment better fits the pattern of the data.

%out obtained when applying the different restrictions

The %out without any restriction was obtained, as well as after applying each of the three restrictions individually (Table 3). Restrictions (i) and (ii) reduce the %out, while restriction (iii) increases the %out.

Table 3 shows effects are mitigated or amplified when the various constraints are combined or modified (see Table 1). In general, it is observed that whenever restriction (iii) is included, the results worsen (%out increases), regardless of whether one, two or none of the other restrictions are applied. As for restrictions (i) and (ii), while both are effective in reducing %out, it is observed that restriction (ii) has a greater impact, causing greater decreases in the %out as the minimum distance between consecutive drop heights is increased. Due to the impossibility of presenting all the results, Table 3 shows the combination that modifies the current method as little as possible and achieves fewer %out. This combination also reduces the %out of the current method (Table 2).

Three-drop versus two-drop test method

CFH results and the outliers obtained with the two-drop method are shown in Table 4. The comparison

Table 2. Descriptive statistics of the CFH values obtained when using the linear and quadratic adjustments with the current method restrictions.

Field	n	Linear				Quadratic			
		Mean	SD	out	CV	Mean	SD	out	CV
Field 1	802	1.215	0.018	0	0.015	1.256	0.022	0	0.017
Field 2	844	1.329	0.015	3	0.011	1.356	0.020	0	0.015
Field 3	883	0.867	0.014	0	0.017	0.913	0.013	1	0.014
Field 4	926	1.289	0.022	51	0.017	1.292	0.036	4	0.028
Field 5	347	1.371	0.021	5	0.015	1.402	0.036	0	0.026
Field 6	754	1.307	0.027	13	0.020	1.299	0.054	13	0.041
Field 7	794	1.375	0.017	8	0.012	1.398	0.022	5	0.016

The n changes among fields because when applying the restrictions, different numbers of observations are left out.
n: number of combinations; SD: standard deviation; out: number of outliers; CV: coefficient of variation.

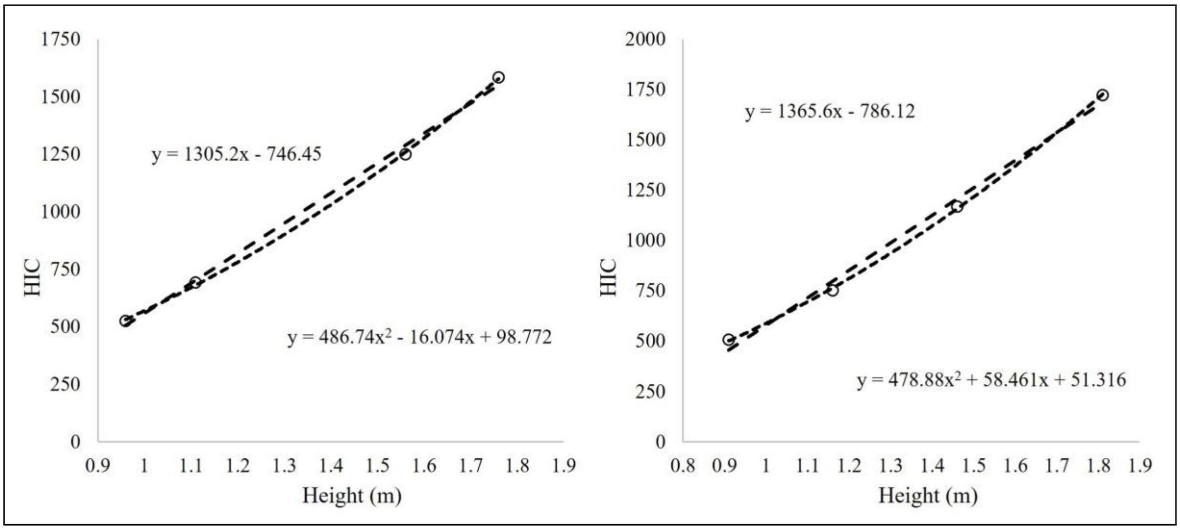

Figure 3. Linear and quadratic adjustments from different examples.

with the best method in Table 4 showed that the use of the two-drop method does not increase the %out.

Table 5 presents the inter-method agreement and reliability. Results of the Bland–Altman test show modest deviations between the three-drop and the two-drop methods for the CFH assessment, and ICC values show excellent reliability (ICC ø 0.75) between the two test methods. Also, the results of the product-moment correlation (r) show a close relationship between measures obtained with both methods.

Plots obtained through the Bland–Altman analysis are presented in Figure 4. The results indicate a slight overestimation of CFH values when obtained with the two-drop method.

Discussion

This study aimed to analyse World Rugby's current Test Method 01 head injury criteria (HIC), which consider a field as unsafe if the CFH is below 1.3 m. Results show that outliers in quadratic factor are lower than the linear factor. Therefore, quadratic estimation improves the linear method, while the rest of the quality indicators remain similar.

In relation to the effectiveness of the different restrictions of the method to reduce the percentage of outliers, we investigated them individually. To do so, the %out obtained when gradually applying each restriction was compared to the %out obtained when applying no restrictions (%out$_{ref}$). The following conclusions were obtained from the analyses performed above:

- Restriction (i): the %out is reduced as the maximum distance between the highest and the lowest drop heights decreases.
- Restriction (ii): the %out is reduced as the minimum distance between drop heights increases.
- Restriction (iii): the %out is reduced as the restricted area around 1000 is reduced.

Between the two restrictions that improved %out$_{ref}$, the lowest %out was obtained by applying restriction (ii), and thus by restricting the minimum distance between drop heights. Due to the particularities of the test

Table 3. Descriptive statistics of the CFH values obtained when different restrictions are applied.

	Field	n	Mean (m)	SD (m)	out	%out (%)	CV
No restrictions	Field 1	5148	1.258	0.033	227	4.409	0.026
	Field 2	5148	1.356	0.032	213	4.138	0.024
	Field 3	5148	0.913	0.020	262	5.089	0.022
	Field 4	5148	1.297	0.053	286	5.556	0.041
	Field 5	5148	1.389	0.061	171	3.322	0.044
	Field 6	5148	1.312	0.069	230	4.468	0.053
	Field 7	5148	1.402	0.038	312	6.061	0.027
Only restriction (i)	Field 1	4053	1.254	0.030	149	3.676	0.024
	Field 2	4053	1.359	0.029	149	3.676	0.021
	Field 3	4053	0.914	0.018	173	4.268	0.020
	Field 4	4053	1.295	0.052	224	5.527	0.040
	Field 5	4053	1.383	0.050	109	2.689	0.036
	Field 6	4053	1.316	0.070	171	4.219	0.053
	Field 7	4053	1.397	0.035	218	5.379	0.025
Only restriction (ii)	Field 1	1466	1.257	0.022	6	0.409	0.017
	Field 2	1515	1.357	0.021	2	0.132	0.015
	Field 3	1657	0.913	0.013	10	0.604	0.014
	Field 4	1457	1.294	0.039	10	0.686	0.030
	Field 5	1419	1.384	0.040	10	0.705	0.029
	Field 6	1515	1.320	0.058	18	1.188	0.044
	Field 7	1457	1.398	0.025	17	1.167	0.018
Only restriction (iii)	Field 1	4356	1.258	0.033	227	5.211	0.026
	Field 2	4356	1.356	0.032	211	4.844	0.024
	Field 3	4356	0.913	0.020	262	6.015	0.022
	Field 4	5148	1.297	0.053	286	5.556	0.041
	Field 5	2475	1.389	0.061	156	6.303	0.044
	Field 6	4356	1.312	0.069	209	4.798	0.053
	Field 7	4356	1.402	0.038	311	7.140	0.027
Best restriction combination	Field 1	460	1.253	0.020	0	0.000	0.016
	Field 2	484	1.355	0.018	0	0.000	0.013
	Field 3	490	0.913	0.013	0	0.000	0.014
	Field 4	512	1.290	0.032	0	0.000	0.025
	Field 5	480	1.383	0.035	1	0.208	0.025
	Field 6	488	1.320	0.054	6	1.230	0.041
	Field 7	494	1.397	0.021	0	0.000	0.015

No restrictions, use all possible combinations of four heights with two HIC values below and above 1.00 m. The best restriction combination uses restriction (i) and restriction (ii) with the higher distance between drops adjusted to 0.20 m. The n changes between the fields because when applying the restrictions, different numbers of observations are left out.
n: number of combinations; SD: standard deviation; out: number of outliers; %out: percentage of outliers; CV: coefficient of variation; SEM: standard error of measurement.

Table 4. Descriptive statistics of the CFH values obtained when using the improved combination of restrictions and the two-drop test method.

Restriction (i) and restriction (ii) with the higher distance between drops adjusted to 0.20 m						
Field	n	Mean (m)	SD (m)	out	%out	CV
Field 1	475	1.276	0.023	0	0.000	0.018
Field 2	484	1.376	0.016	0	0.000	0.011
Field 3	489	0.936	0.014	0	0.000	0.014
Field 4	512	1.326	0.028	0	0.000	0.021
Field 5	480	1.379	0.037	0	0.000	0.027
Field 6	482	1.320	0.054	6	1.245	0.041
Field 7	494	1.421	0.026	0	0.000	0.018

The n changes between the fields because when applying the restrictions, different numbers of observations are left out.
n: number of combinations; SD: standard deviation; out: number of outliers; %out: percentage of outliers; CV: coefficient of variation; SEM: standard error of measurement.

method and the characteristics of the test equipment, it was not recommended to abruptly increase the space between test heights, because the apparatus would end up suffering from too high impacts in the last test

Table 5. Agreement and reliability between test methods for the assessment of the CFH.

Field	n	Bias (m)	Random error	ULA (m)	LLA (m)	r	ICC
Field 1	341	0.019	0.012	0.042	−0.004	0.84	0.91
Field 2	484	0.021	0.008	0.036	0.005	0.90	0.94
Field 3	449	0.025	0.004	0.033	0.017	0.95	0.98
Field 4	512	0.036	0.015	0.065	0.007	0.89	0.94
Field 5	480	−0.004	0.006	0.008	−0.015	0.99	0.99
Field 6	488	0.000	0.002	0.004	−0.004	1.00	1.00
Field 7	494	0.025	0.016	0.056	−0.007	0.78	0.86

The n changes between the fields because when applying the restrictions, different numbers of observations are left out.
n: number of combinations; Bias: average difference between methods (two-drop and three-drop); ULA: upper limit of agreement; LLA: lower limit of agreement; r: product-moment correlation coefficient; ICC: intraclass correlation coefficient.

heights. Therefore, considering the results obtained, applying an increase from 0.15 to 0.20 m in restriction (ii) was considered the most appropriate.

Then, to investigate the %out when applying the restrictions combined, the %out when adopting only restriction (ii) was taken as a new reference, and the %out also considering restrictions (i) and (iii), independently and combined, was calculated.

As a result of the above, the following conclusions were obtained:

- Adding restriction (i) to restriction (ii) slightly reduces the %out, thereby improving the test method. The stricter restriction (i) is, the better.
- Adding restriction (iii) to restriction (ii) worsens or improves almost negligibly, the %out.
- Adding restriction (iii) in comparison with using only the last two (i and ii).

Therefore, the best approach to reduce the %out and improve the repeatability of the test method was to strengthen restriction (ii), keeping restriction (i) as tight as possible and eliminating restriction (iii), as shown in Table 3.

Finally, a second objective of the present study was to investigate the possibility of simplifying -the test method. Because the current procedure requires that three-drop tests must be performed in the same test point and results of the second and third drops were reasonably close, the most appropriate approach to simplify the test method was to investigate the results when eliminating the third drop, therefore considering the HIC value for a certain height as the highest HIC of those obtained in the first two-drops.

When comparing the CFH values obtained with both methods (Tables 3 and 4), our results show that reducing the number of drop tests from three to two per test point does not affect the %out obtained, and therefore does not affect the repeatability of the method. Moreover, the results of the Bland–Altman test show only slight deviations between the two test methods, showing that the three-drop and the two-drop methods provide similar results when assessing CFH in sports surfaces. Also, the overall results of the linear regression analysis (r value) indicate an excellent replication of the three-drop outcomes when using the two-drop method. Thereby, the two-drop and the three-drop methods can be used interchangeably when assessing CFH on artificial turf rugby surfaces.

Finally, considering the data from the seven fields used in this study, the mean CFH calculated with the actual method underestimates the test results compared to the new proposed method (mean difference of 0.05 m). CFH regulatory requirement for artificial turf rugby surfaces us 1.3 m. These surfaces are very close to the allowed threshold. Thereby, some surfaces that potentially pass the new methods requirements may not pass these requirements with the actual one. These results show that the competent authorities may decide about the new proposed method.

This study used field data from seven different artificial turf rugby fields, chosen randomly to cover different scenarios, including fields that are compliant or close to compliant (most frequent circumstances). Although the proposed method consistently improves on all surfaces, regardless of their consistency, it will be necessary to compare these results by carrying out tests by different technicians on the same surface.

Conclusion

Based on the results above, it can be concluded that the current Test Method 01 for the determination of CFH using HIC in artificial turf rugby fields can be both improved and simplified. The method can be improved by applying two main modifications. First, the linear adjustment currently required for the calculation of the CFH should be replaced with a quadratic adjustment (more precision in the estimation and therefore less error in estimating the injury chances by the CFH). Second, the current test restrictions should be adapted as follows: maintaining the maximum difference between the highest and the lowest drop heights at 1.00 m, increasing the minimum difference between consecutive drop heights from 0.15 to 0.20 m and removing the current prohibition on obtaining HIC values close to 1000. These modifications will improve the repeatability of the current test method and decrease

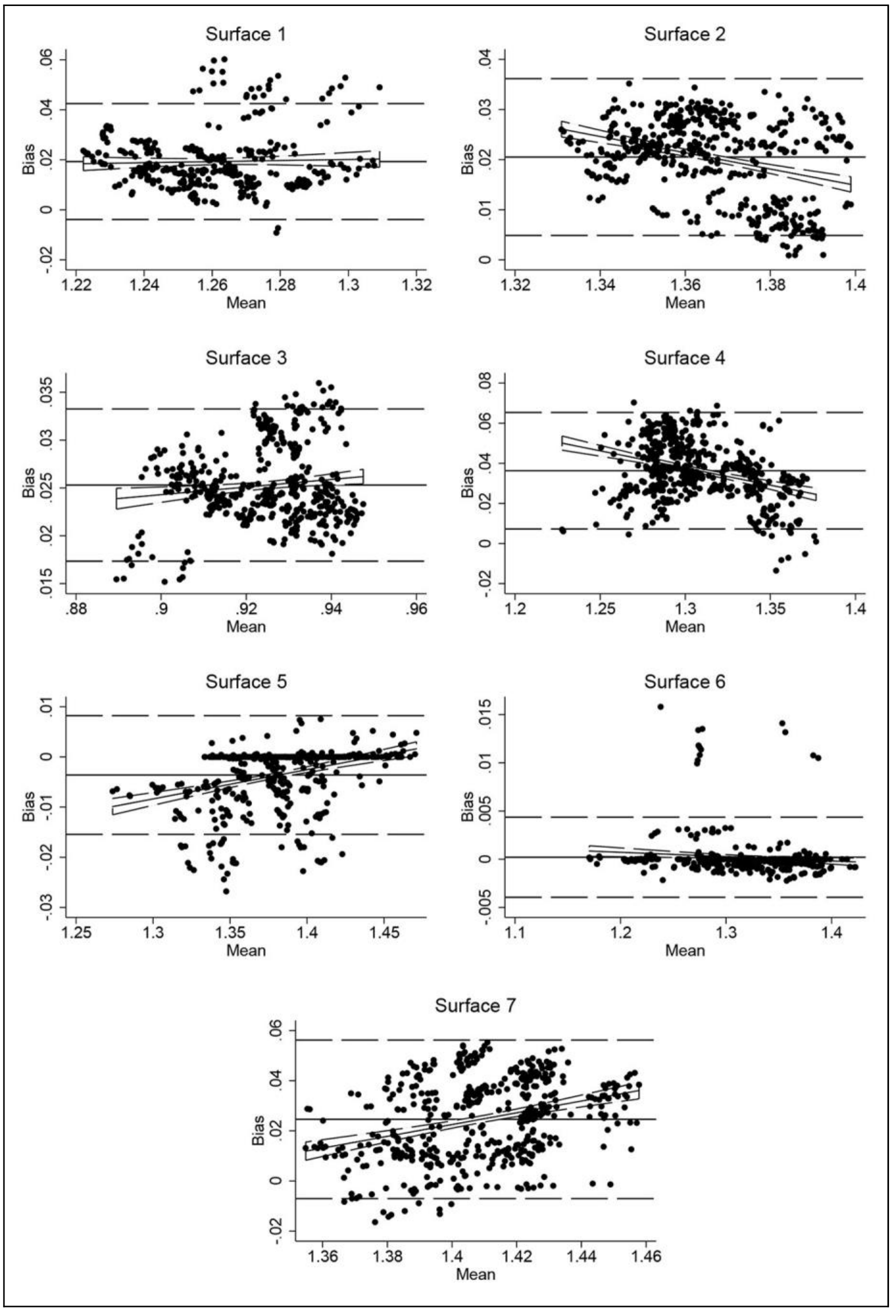

Figure 4. Bland-Altman plots identifying differences when comparing CFH results with the three-drop and the two-drop methods. Central line represents the inter-method difference (bias). Upper and lower lines represent the 95% limits of agreement (bias 6 1.96 SD of the differences). The tendence line represent the correlation between bias and men and 95% confidence interval.

the percentage of atypical results. Furthermore, the test method can be simplified by dispensing with the third drop test and performing only two-drop tests per test point. This situation can save technicians a considerable amount of time without significantly affecting test results.

Declaration of conflicting interests

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