BJSM Online First, published on February 21, 2014 as 10.1136/bjsports-2014-093412

Visual or computer-based measurements: important for interpretation of athletes' ECG

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▸ Additional material is published online only. To view please visit the journal online (http://dx.doi.org/10.1136/bjsports-2014-093412)

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Accepted 1 February 2014

To cite: Berge HM, Steine K, Andersen TE, *et al*. *Br J Sports Med* Published Online First: [*please include* Day Month Year] doi:10.1136/bjsports-2014-093412

ABSTRACT

Background ECG is recommended for preparticipation health examination in athletes. Owing to a lack of consensus on how to read and interpret athletes' ECGs, different criteria for abnormality are used.

Aims To compare the prevalence of abnormal ECGs and test the correlation between visual and computer-based measurements.

Methods In a preparticipation cardiac screening examination of 595 male professional soccer players aged 18–38 years, ECGs were categorised according to the European Society of Cardiology's (ESC) recommendations and the Seattle criteria, respectively. Visual measurements were conducted with callipers on-screen on the averaged PQRST complex in each lead, calculated by the trimmed mean. Computer-based measurements were derived from the medium beat. Heart rhythm and conduction were scored visually by a cardiologist. Categorical variables were compared by κ statistics (K) and continuous variables by intraclass correlation.

Results ECGs of good quality were available from 579 players. According to the ESC's recommendations and Seattle criteria, respectively, ECGs were categorised as abnormal in 171 (29.5%) vs 64 (11.1%) players after visual assessment, and in 293 (50.6%; K=0.395) vs 127 (21.9%; K=0.564) after computer-based measurements. Intraclass correlation was very good for measurements of R and S wave amplitudes and moderate to very good for intervals. K was very good for pathological Q wave amplitudes and moderate for T wave inversions.

Conclusions Abnormal ECGs were more than twice as common after computer-based than after visual measurements. Such a difference will markedly influence the number of athletes who need further examinations. Reference values may need adjustments dependent on measurement methods.

INTRODUCTION

ECG is recommended by the European Society of Cardiology (ESC) and the International Olympic Committee as part of preparticipation health examination in athletes.[1 2] Whether and to what extent an athlete's ECG is defined as abnormal depends on the measurement method and the interpretation criteria.

Before the digital era, the only widely accepted written recommendations for ECG interval measurement were based on three consecutive sinus complexes, preferably from lead II.[3] Today, averaged beats are often used, and the durations are derived from the global intervals,[3] which are measured from the earliest wave onset to the latest offset in any lead (figure 1).[4] The isoelectric baseline in an ECG is invisible, and must be defined to permit amplitude measurements.[5] Whether the PR line or the TP segment is chosen as the reference line will influence the results. Comparison of studies is difficult because many investigators do not report their method of measurement and because ECG devices are programmed differently.[6]

The main aim of this study was to compare the prevalence of abnormal ECG findings between visual and computer-based measurements, according to the ESC's recommendations as specified by Uberoi *et al*,[7] and the new Seattle criteria for interpreting ECG,[8] in male professional soccer players in Norway. To facilitate meaningful comparison with other studies, the performance of the ECG sampling and measuring procedures are described in detail.

METHODS

Participants

In total, 595 male professional soccer players in Norway underwent mandatory preparticipation cardiac screening during a preseason training camp in 2008. Players responded to a questionnaire regarding their height, weight and ethnicity. All participants gave informed written consent.

Blood pressure and ECG

Blood pressure (BP) was measured at least 1 h after exercise and after 5 min rest in a sitting position, using a validated automatic BP monitor (Dinamap ProCare DPC300N, GE, Milwaukee, Wisconsin, USA), and registered as the mean of two consecutive BP recordings.

With the player in a supine position, the precordial ECG electrodes were placed according to recommendations,[4] and the four limb lead electrodes were placed on the arms and legs just distal to the shoulders and hips. ClickECG (Cardiette Cardioline, Milan, Italy) with Real Click software V.3.2.10 collected the simultaneous 10 s digital recordings with a front-end sampling rate of 2000 per second and compression ratio of 4:1. Paper speed was 25 mm/s with 10 mV gain. The frequency response was 0.05–150 Hz, the baseline filter was always on, the network filter was set at 50 Hz and the muscular filter at 40 Hz. The filtered signals were stored.

The software recognised waveforms with amplitudes of at least 25 μV and durations of at least 6 ms. After QRS was detected and classified, a medium beat for all leads was built from every sinus complex (see online supplementary figure S1) and fiducial points and measurements were computed and stored in the measurement table (see online supplementary figure S2). The averaged PQRST complex in each lead was calculated by the

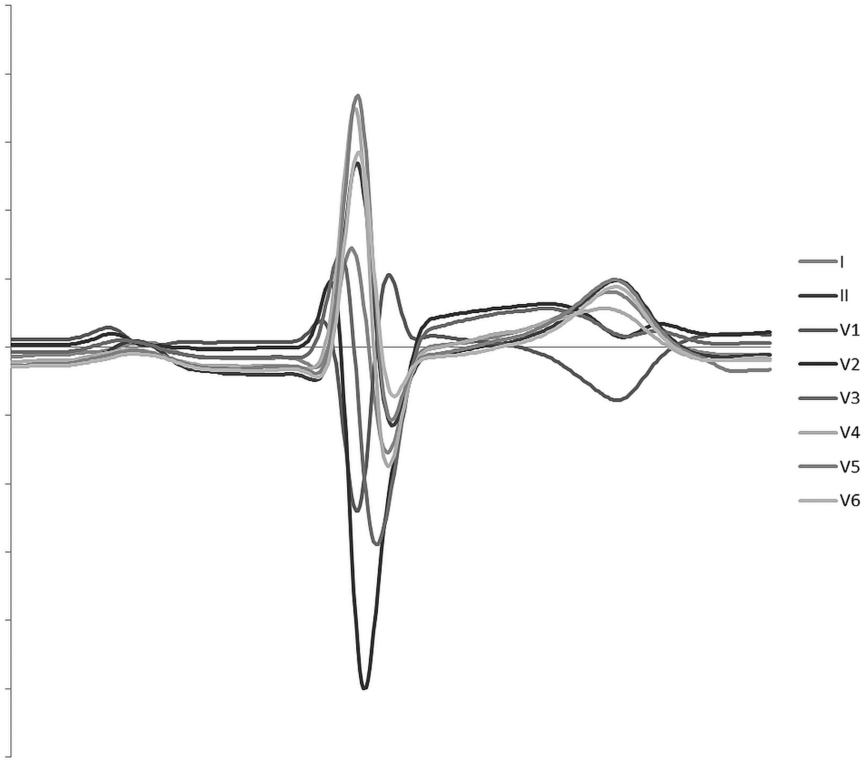

Figure 1 Superimposed global PQRST complex (SGC) computed from eight leads' raw data in the ECG recording of a 20-year-old-professional white male Norwegian soccer player.

trimmed mean, discarding the first and last quartile of the data (see online supplementary figure S3). The superimposed global complex (SGC) was composed of 12 representative beats superimposed from each of 12 leads (figure 1), and durations were measured from the earliest onset to the latest offset in the SGC and stored in the database (see online supplementary figure S4).

The visual analysis was performed on 100–400% magnified signals on a 24″ screen with 1680×1050 MPixel resolution, using on-screen callipers (Real Click, software V.3.5.4.): the P wave, PR interval and QRS duration were measured to the nearest 2 ms from the average PQRST complex in lead II. If the PR interval was <120 ms in lead II, all leads were measured. The PR interval was categorised as short if <120 ms in all leads. The R and S wave amplitudes were measured to the nearest 1 μV as the mean of the highest amplitudes in the QRS complexes (see online supplementary figure S5), and the maximum P wave amplitude was measured in lead II. Intraventricular conduction delay was diagnosed if the QRS duration in lead II was >120 ms according to the specified ESC recommendations, or if the computer-derived QRS duration was ≥140 ms after visual assessment of first onset to last offset in the SGC.[9] The offset of the QT interval was adjusted visually using the intersection between a tangent drawn from the descending part of the T wave to the horizontal line drawn between the PR intervals in lead II, V_3 or V_5 (see online supplementary figure S3). QTc was defined according to Bazett's formula and categorised as prolonged if ≥470 ms in any lead. The QT duration was visually assessed in all leads if QT was ≤330 ms or QTc <340 ms (ESC recommendations), or ≤320 ms (Seattle criteria), and only regarded as short if these criteria were fulfilled in all leads. The following amplitudes were visually assessed and measured with on-screen callipers in the separate leads if borderline: ST segment depression was categorised as >0.5–1 or >1 mm in any lateral leads (I, aVL, V_5 or V_6) and >1 mm in any other lead, whereas ST segment elevation was categorised as >1 mm, pathological T wave inversion as >1 mm (or negative part of biphasic T wave >1 mm) and pathological Q wave amplitudes as ≥3 mm and/or ≥40 ms in duration. All amplitudes were related to the PR line.

Heart rate in beats per minute (bpm) and QRS axis in degrees were derived from the computer and visually confirmed.

For detailed differences between the specified ESC recommendations and the Seattle criteria, see online supplementary tables S1–S3.

Clinical and ECG interpretations

On site, experienced cardiologists decided if the players were eligible for professional soccer based on their medical history, physical examination, ECG and echocardiographic evaluation with standard measurements.[10] For the present study, all ECGs were assessed and measured by one investigator (HMB), who also developed separate syntaxes adjusted to the different criteria, and possible rhythm or conduction disturbances were discussed with a cardiac electrophysiologist (KG). The ECGs were categorised as normal, including common and training-related ECG changes, or abnormal.

Adjusted reference values for computer-based measurements

When the main differences between visual and computer-based measurements were displayed, reference values were adjusted for computer-based measurements to obtain better agreement to visual analyses.

Data analysis

Since most of the ECG measurements had non-Gaussian distribution, data are presented as medians and IQRs, (for mean ±SD, see online supplementary table S4). Intraclass correlations (ICC) were used to test correlations for continuous variables and κ statistics to test agreement between categorical variables.

Table 1 Agreement between visual and computer-based abnormal ECG findings in 579 athletes: numbers and percentages (%) of patterns suggestive of cardiomyopathy according to the specified ESC's recommendations, compared to the new Seattle criteria for ECG interpretations in athletes

	ESC with specifications			Seattle criteria		
	Visual	Computer	K value	Visual	Computer	K value
Abnormal ECG findings						
T wave inversions	69 (11.9)	106 (18.3)	0.579	27 (4.7)	50 (8.6)	0.599
ST segment depressions	12 (2.1)	29 (5.0)	0.372	2 (0.3)	25 (4.3)	
Pathological Q wave amplitudes	25 (4.3)	30 (5.2)	0.828	19 (3.3)	19 (3.3)	0.946
Pathological Q wave durations		96 (16.6)			34 (5.9)	
Complete left bundle branch block	0	0		0	0	
Intraventricular conduction abnormalities	26 (4.5)	124 (21.4)		4 (0.7)	10 (1.7)	
Left-axis deviation	5 (0.9)	5 (0.9)		6 (1.0)	6 (1.0)	
Left atrial enlargement	1 (0.2)	1 (0.2)		1 (0.2)	1 (0.2)	
Right atrial enlargement	33 (5.7)	5 (0.9)				
Right-axis deviation	5 (0.9)	5 (0.9)		5 (0.9)	5 (0.9)	
Left posterior hemiblock	4 (0.7)	3 (0.7)		4 (0.7)	4 (0.7)	
Extreme axis deviation	0	0		0	0	
Right ventricular hypertrophy in athletes ≥30 years old	13 (2.2)	9 (1.6)	0.722	1 (0.2)	1 (0.2)	
Right ventricular hypertrophy in athletes <30 years old	14 ((2.4)	16 (2.8)	0.726	2 (0.3)	2 (0.3)	
Premature ventricular contractions	1 (0.2)	1 (0.2)		1 (0.2)	1 (0.2)	
Ventricular arrhythmias	1 (0.2)	1 (0.2)		1 (0.2)	1 (0.2)	

Blank, not applicable.
ESC, European Society of Cardiology.

Intraobserver variability of visual analysis according to the Seattle criteria was tested 9 months apart from 30 randomly selected players. κ and ICC <0.2 represent poor, 0.21–0.40 fair, 0.41–0.60 moderate, 0.61–0.80 good and >0.8 very good correlation, respectively. Bland-Altman plots were performed between visual and computer-based measurements, and all outliers were visually assessed to decide if waves were misclassified by the computer. Two-tailed $p<0.05$ was considered statistically significant. All statistical analyses were conducted using SPSS (PASW Statistics V.21; IBM Corporation 2013, New York, USA).

RESULTS

Computerised ECG of good quality was available from 579 (97%) of the 595 players (97%) who consented to participate. Their median age was 25 years (21–28), height 183 cm (179–187) and weight 79 kg (74–84). The skin colour was white in 492 (85%), black in 46 (7.9%), mixed for 13 (2.2%) and other for 28 (4.8%). The median heart rate was 55 bpm (49–61), QRS axis 79° (64–89) and QRS duration from the SGC 110 ms (100–120). On site, all players received medical clearance and were eligible to play soccer, except two with BP ≥160/100 mm Hg and left ventricular hypertrophy on echocardiography who were temporarily restricted and received treatment.

ECG findings according to the Seattle and ESC criteria

Changes suggestive of cardiomyopathy are presented in table 1 and primary electrical disease in table 2. According to the specified ESC recommendations, ECGs were categorised as abnormal in 171 (29.5%) players after visual assessment versus 293 (50.6%) after computer-based measurements (figure 2).

Table 2 Agreement between visual and computer-based abnormal ECG findings in 579 athletes: numbers and percentages (%) of patterns suggestive of primary electrical disease according to the specified ESC's recommendations, compared to the new Seattle criteria for ECG interpretations in athletes

	ESC with specifications		Seattle criteria	
	Visual	Computer	Visual	Computer
Abnormal ECG findings				
Ventricular pre-excitation	1 (0.2)	1 (0.2)	1 (0.2)	1 (0.2)
Long QT interval	2 (0.3)	2 (0.3)	2 (0.3)	2 (0.3)
Short QT interval	4 (0.7)	7 (1.2)	1 (0.2)	3 (0.5)
Brugada-like ECG pattern	0	0	0	0
Profound sinus bradycardia	0	0	0	0
Atrial tachyarrhythmias	0	0	0	0
Premature ventricular contractions	1 (0.2)	1 (0.2)	1 (0.2)	1 (0.2)
Ventricular arrhythmias	1 (0.2)	1 (0.2)	1 (0.2)	1 (0.2)
Mobitz type II second-degree AV block	2 (0.3)	2 (0.3)	2 (0.3)	2 (0.3)

AV, atrioventricular; ESC, European Society of Cardiology.

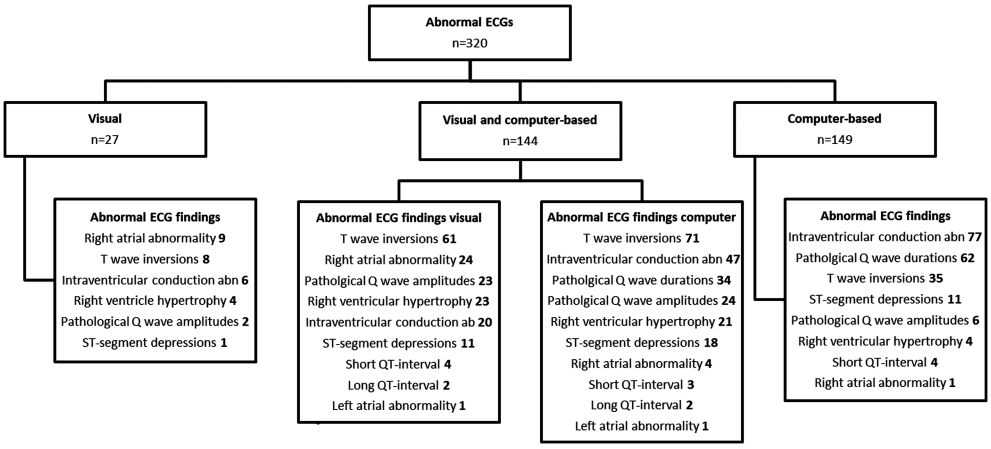

Figure 2 Flow chart showing the distribution of differences in abnormal ECG findings according to the specified European Society of Cardiology (ESC) recommendations between visual and computer-based interpretations in 579 male professional soccer players in Norway.

According to the Seattle criteria, ECGs were categorised as abnormal in 64 (11.1%) players after visual assessment versus 127 (21.9%) after computer-based measurements (figure 3). Normal ECG findings are presented in table 3.

Correlation and agreement between visual and computer-based measurements

Table 4 presents ICC between visual and computer-based measurements for durations and amplitudes in separate leads. For all R and S wave amplitudes, correlations were very good with ICC ranging from 0.946 to 0.996. For abnormal ECG findings suggestive of cardiomyopathy, the agreement between visual and computer-based findings was very good for pathological Q wave amplitudes, good for pathological right ventricular hypertrophy, moderate for T wave inversions and fair for ST segment depression (table 1).

Adjusted reference values for computer-based measurements

The reference values of the variables which accounted for the majority of differences between visual and computer-based measurements were adjusted: pathological Q wave durations to ≥50 ms, T wave inversions to ≥1 mm after subtraction of the J amplitude in the same lead (see online supplementary figure S6), ST segment depression to ≥1 mm regardless of the lead, and intraventricular conduction abnormality as QRS duration in the SGC >130 ms according to the specified ESC recommendations. The prevalence of abnormal ECGs was then reduced to 210 (36.3%) and 73 (12.6%) according to the specified ESC recommendations and Seattle criteria, respectively (see online supplementary table S5, figures S7 and S8). Agreement to visual abnormal ECGs increased to moderate (K=0.560) and good (K=0.777).

Intraobserver variability

Correlations for visual measurements of durations and amplitudes in ECG from 30 randomly selected players were very good, except for QRS duration in lead II with ICC 0.621 (see online supplementary table S6). Five ECGs were interpreted as abnormal each time according to the Seattle criteria (K=1.00).

Computer errors

After assessment of the Bland Altman plots, seven ECGs were excluded from analyses of R and S wave amplitudes because the S waves were misclassified as Q waves in any precordial lead. Visually measured duration of P waves and PR intervals were missing from 21 players and computer-based from 42 players because of irregular rhythm. After visual assessment, 102 computer-based Q waves were corrected, mostly in lead aVL where they had been misclassified as S waves.

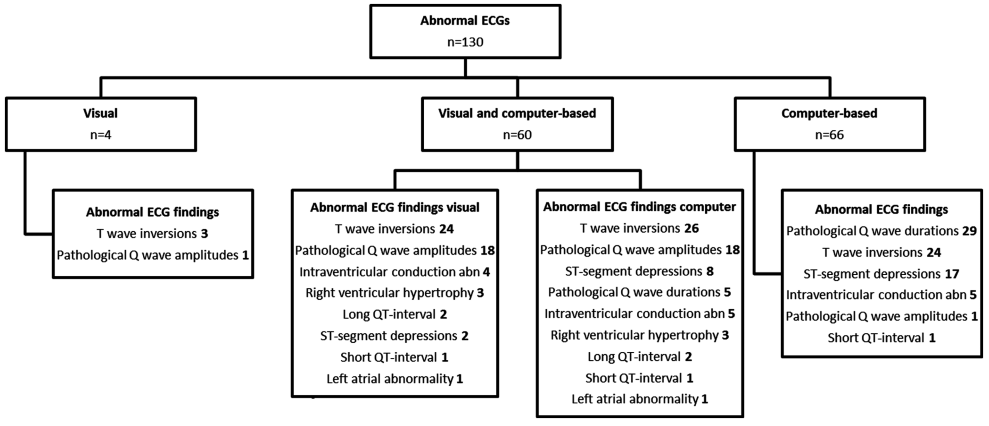

Figure 3 Flow chart showing the distribution of differences in abnormal ECG findings according to the Seattle criteria between visual and computer-based interpretations in 579 male professional soccer players in Norway.

Table 3 Agreement between visual and computer-based normal ECG findings in 579 athletes: numbers and percentages (%) of common and training-related changes according to the specified ESC's recommendations, compared to the new Seattle criteria for ECG interpretations in athletes

	ESC with specifications			Seattle criteria		
	Visual	Computer	K value	Visual	Computer	K value
Normal ECG findings						
Sinus bradycardia	396 (68.4)	396 (68.4)		396 (68.4)	396 (68.4)	
Sinus arrhythmia	220 (38.0)	220 (38.0)		206 (35.6)	206 (35.6)	
Ectopic atrial rhythm	8 (1.4)	8 (1.4)		8 (1.4)	8 (1.4)	
Junctional escape rhythm	12 (2.1)	12 (2.1)		12 (2.1)	12 (2.1)	
First-degree AV block	29 (5.0)	24 (4.1)	0.822	70 (12.1)	56 (9.7)	0.751
Mobitz type I second-degree AV block	3 (0.5)	3 (0.5)		3 (0.5)	3 (0.5)	
Incomplete right bundle branch block	23 (4.0)	22 (3.8)	0.330	67 (11.6)	46 (7.9)	0.697
Isolated QRS voltage criteria for left ventricle hypertrophy	103 (17.8)	68 (11.7)	0.489	116 (20.0)	114 (19.7)	0.718
Early repolarisation	532 (91.9)	558 (96.4)	0.381	397 (68.6)	499 (86.2)	0.405
Common ST–T wave changes in black/other athletes	22* (25.3)	38* (43.7)	0.650	22* (25.3)	38* (43.7)	0.650

Blank, not applicable.
*N=87.
AV, atrioventricular; ESC, European Society of Cardiology.

DISCUSSION

The present study is the first to correlate visual and computer-based measurements in a homogeneous group of athletes. The prevalence of abnormal ECGs in male professional soccer players in Norway was twice in computer-based versus visual analyses, and was up to threefold more common when interpreted according to the ESC's recommendations compared to the Seattle criteria. Agreement increased to moderate and good after adjustment of reference values for the most common computer-based abnormal ECG findings.

Visual versus computer-based interpretations

Benefits and risks

If correct, computer-based interpretation of athletes' ECG in preparticipation health examinations should be preferred. Studies in the general population indicate that computer-based interpretations can increase the prevalence of correct conclusions by the physicians by 28%,[11] reduce the time needed to interpret ECG by up to 28%,[12] and reduce variability due to disagreement and different interpretation skills between physicians.[13] Computer-based algorithms also have more sophisticated calculations of amplitude-duration products and risk scores for sudden cardiac death.[14] Still, Gademan *et al*[15] advised caution with computerised ECG measurements because they detect small, insignificant abnormalities that are 'missed' or usually regarded as normal by the physicians,[13] as was the case in the present study for 122 ECGs according to the specified ESC recommendations and 63 ECGs according to the Seattle criteria.

Table 4 ECG measurements in 579 professional male soccer players in Norway

	Computer	Visual	ICC (95% CI)	Mean±SD
Intervals in lead, in ms*				
II: P wave	114 (104–124)	104 (94–114)	0.691 (0.644 to 0.734)	109±15
II: PR interval	164 (148–178)	164 (147–182)	0.937 (0.925 to 0.947)	167±29
II: QRS duration	102 (98–108)	98 (89–108)	0.475 (0.410 to 0.536)	101±10
II: QT interval	416 (398–440)	400 (380–422)	0.886 (0.867 to 0.903)	410±31
V_3: QT interval	414 (396–438)	375 (350–397)	0.834 (0.804 to 0.859)	396±31
V_5: QT interval	414 (396–436)	398 (378–420)	0.920 (0.906 to 0.932)	408±32
Amplitudes in lead, in μV†				
V_1: R wave	263 (180–398)	252 (172–383)	0.991 (0.989 to 0.992)	3.0±1.8
V_1: S wave	−852 (−1178–(−559))	−809 (−1149–(−543))	0.994 (0.993 to 0.995)	−9.1±5.3
V_2: R wave	638 (440–880)	632 (432–867)	0.994 (0.993 to 0995)	6.8±3.2
V_2: S wave	−1845 (−2393–(−1344))	−1785 (−2346–(−1285))	0.996 (0.996 to 0.997)	−18.5±7.9
V_3: S wave	−850 (−1235–(−513))	−820 (−1200–(−475)	0.994 (0.993 to 0.995)	−9.4±6.4
V_5: R wave	1868 (1515–2308)	1860 (1502–2282)	0.946 (0.937 to 0.954)	19.2±5.8
V_5: S wave	−218 (−353–(−115))	−202 (−340–(−100))	0.989 (0.987 to 0.991)	−2.5±2.0
V_6: R wave	1415 (1153–1788)	1397 (1137–1750)	0.954 (0.946 to 0.961)	14.7±4.7
V_6: S wave	−138 (−245–(−58))	−132 (−231–(−42))	0.987 (0.985 to 0.989)	−1.7±1.7
aVL: R wave	109 (72–173)	102 (57–162)	0.968 (0.962 to 0.973)	1.3±1.1

Values are presented as medians (IQR), and mean (computer+visual/2)±SD.
*Intervals measured visually from the average PQRST complex in the respective lead.
†Amplitudes measured visually as the mean of the highest amplitudes.

Effects of adjustment of computer-based reference values

Measurements of ST-T wave changes showed lowest sensitivity and specificity in a study of reliability and accuracy of computer programs.[16] In the present soccer players, where early repolarisation was common (86–96%), choice of baseline will influence the results in both directions. The agreement increased when the computer subtracted the J amplitude from T wave inversions ≥1 mm in the same lead.

Most of the computer-based pathological ST segment depressions were <1 mm. Adjusting the threshold for abnormal values to >1 mm prevented errors due to small deflections that were visually difficult to verify.

As expected, we found more intraventricular conduction delay after computer-based measurements, since durations derived from the SGC must be equal to or greater than measurements in one lead. The median value for the abnormal computer-based QRS durations (ie, >120 ms, n=124) was 126 ms (124–130); hence, by adjusting the threshold to >130 ms, only 29 were categorised as abnormal according to the specified ESC recommendations.

Differences between the ESC recommendations and the Seattle criteria

Reference values for abnormal ECG findings in athletes are based on consensus. The number of athletes who require additional cardiac testing due to an abnormal ECG is highly influenced by the choice of criteria, and varies from 4.5% to 23% in other studies.[17 18]

The Italian screening programme, to which the European recommendations frequently refer, has mostly been based on precordial single-lead amplitudes,[19] while the new Seattle criteria take into account that abnormal durations or intervals should be present and consistent in different complexes across different leads,[5] and then be less susceptible to misclassifications. With regard to the Seattle criteria, we agree with other authors that ECGs interpreted as normal by the computer need not to be visually assessed, thereby speeding up the time for analysis.[5 16]

Visual or computer-based measurements

Overall, the weakest correlations were found for the QRS duration. This is in contrast to a study by Cheng *et al* that showed that when physician-derived and computer-derived QRS durations were available on the same ECGs, the correlation between techniques was high (r=0,81, p<0.001).[20] They measured 'to the end of the R or S wave'—an end that in our experience is hard to define when it is slurred, notched, depressed or elevated. In their study of a community-based cohort, 3% had QRS duration ≥120 ms, compared to 21% in our study. QRS duration is frequently increased in left ventricular hypertrophy,[21] a common training-related change in soccer players, and this may contribute to the increased prevalence of intraventricular conduction delay. Our use of muscular filter may also have widened the QRS complexes.

The median abnormal Q wave duration (≥40 ms) was 45 ms (n=96), a difference not easily visible. The correlations between visual and computer-based QT intervals in lead II, V_3 and V_5 were very good (table 4). If we had used QTc from the SGC to define a long QTc interval, one extra player had been classified with a long QTc interval, with a borderline value of 472 ms. If computer-based values considered out of range were reread visually and corrected, as described by Gademan *et al*,[15] it seems reasonable to trust normal QTc values measured from the SGC.

Intraobserver variability

The intraobserver variability was very good with no case of disparity regarding abnormal ECGs, and ICC >0.900 for amplitudes and intervals, except QRS duration as mentioned earlier. This is in contrast to many other studies where one cardiologist reading the same ECG on separate occasions may have substantially different interpretations.[13]

Limitations

The prevalence of abnormal ECGs from male professional soccer players in Norway is not necessarily representative of athletes in other sporting disciplines or with different age and sex. The results also may have been different if we had used other ECG devices with different processing and interpretation software. In ClickECG, first onset and latest offset of the SGC were indicated in all averaged PQRST complexes, but only one averaged lead was visible each time. Accuracy of interval measurements would have increased with newer software that permits manual adjustment of the demarcation lines in the SGC in all leads synchronously. The application of a 40 Hz muscular filter during the ECG recordings smoothed the amplitudes and broadened the QRS complexes; hence, less abnormality due to high amplitudes or possible epsilon waves were detected, while the threshold for intraventricular conduction delay was exceeded more often.

All ECGs were systematically assessed by one physician only, perhaps increasing the risk for systematic errors but assuring reproducible visual measurement, in contrast to a study that showed that only every third and fourth one among 158 doctors correctly marked the PR and QT intervals, respectively.[22]

Clinical impact and conclusions

This study demonstrates that with adjusted reference values for computer-based ECG findings, the agreement between visual and computer-based abnormal ECGs is close to very good according to the Seattle criteria, and moderate according to the specified ESC recommendations. The advantage of the Seattle criteria is its requirement of pathological findings in ≥2 leads, reducing the risk of misclassifications and 'borderline' abnormalities. The QTc interval can be automatically measured on the SGC when reread if abnormal. In general, interpretations can rely on computer-based normal findings without missing serious abnormalities in need of follow-up. Disagreements mostly regard 'borderline' ECG findings without clinical significance, except for misclassifications of S as Q waves and vice versa, which has to be improved on by the manufacturer.

Consensus on how to record, measure and interpret athletes' ECG is needed to improve the physicians' diagnoses and accumulate homogeneous databases, which in turn can generate enough statistical power to suggest specific reference values based on sex, ethnicity and sporting disciplines.

What are the new findings?

- This is the first study to compare visual versus computer-based measurements of athletes' ECG.
- Abnormal ECGs were more than twice as common after computer-based versus visual measurements.
- Agreement between visual versus computer-based findings was better for the Seattle criteria than for the European Society of Cardiology's recommendations.

How might it impact on clinical practice in the near future?

- More attention should be paid to the ECG device, recordings and measurement techniques during preparticipation screening.
- Reference values for abnormality might be adjusted depending on measurement methods.
- Computer-based interpretations of normality according to the Seattle criteria might be reliable without further assessment by a physician.

Acknowledgements The Oslo Sports Trauma Research Center has been established through generous grants from the Eastern Norway Regional Health Authority, the International Olympic Committee, the Royal Norwegian Ministry of Culture, Norsk Tipping AS and the Norwegian Olympic Committee & Confederation of Sport. The authors would like to thank all players who participated in the study, the clubs' medical teams, The Soccer Association of Norway, The Professional Norwegian Soccer League, cardiologists and nurses for collecting data and Kristoffer Steine for helping organise the examination, and Professor Ingar M Holme for statistical support.

Contributors HMB designed this part of the study, wrote the statistical analysis plan, cleaned and analysed all the data, developed separate syntaxes adjusted to the different criteria and measurement methods, and drafted and revised the paper. KS, TEA and EES designed the preparticipation study and monitored data collection for the trial, as well as revising the paper. KG analysed the data and drafted and revised the paper.

Funding This research was supported by the Oslo Sports Trauma Research Center, Oslo, and Institute of Clinical Medicine, University of Oslo, Oslo, Norway.

Competing interests None.

Ethics approval The Regional Ethical Committee in Norway.

Provenance and peer review Not commissioned; externally peer reviewed.

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Visual or computer-based measurements: important for interpretation of athletes' ECG

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Br J Sports Med published online February 21, 2014
doi: 10.1136/bjsports-2014-093412