AUTOMATIC SCREENING OF ACCELERATION SIGNAL DURING PIVOT-SHIFT TEST BASED ON PEARSON'S CORRELATION COEFFICIENT

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Abstract: Anterior cruciate ligament injury produces a pathologic kinematics of the limb that can lead to the evidence of a pivot-shift (PS) phenomenon. PS-test, specifically performed to highlighted this knee dynamic instability, is however difficult to quantify. From a clinical point of view is therefore mandatory to find a set of parameters able to quantitatively characterize PS phenomenon, thus distinguishing between pathologic and healthy knees. This study proposed a methodology able to automatically quantify PS phenomenon, analysing the signal recorded by means of a tri-axial accelerometer while executing PS-test itself. A signal template, which reproduced the 3D acceleration average trend while PS phenomenon occurs, was passed along the signal in order to recognise the presence of similar patterns. The recognition of the signal interesting share was based on the calculation of the Pearson's correlation coefficient between the template and the corresponding part of the windowed signal. The data acquisition concerning to the first 35 patients was used to testing the template; in this analysis we considered both the data relative to pathologic and healthy knee, as well as pre- and post-anaesthesia data, in order to evaluate the influence of active muscular resistance. The methodology followed had assured a recognition of PS repetitions with an accuracy of 96.7%, a sensitivity of 81.9% and a specificity of 99.3%; therefore can be considered a valid and easily computable method for the automatic screening of the acceleration signal during PS test. In the future this method will be uptake in order to quantify the possibility to discern between pathologic and healthy knee.

1 INTRODUCTION

Scientific literature agrees with the fact that pivot-shift (PS) phenomenon is one of the essential sign of knee dynamic instability, that can specifically highlight an injury of the anterior cruciate ligament (ACL). Moreover clinical results of PS test are more correlated with functional outcomes, patient's satisfaction, joint instability and relief of symptoms, whereas clinical examinations addressing static instabilities (i.e. Lachman and drawer tests) are less related to patient's subjective status (Kocher, et al., 2009).

The main problem in using PS test is associated to the difficulty of quantifying the test outcome; this difficulty is in fact due to the complexity of the manoeuvre itself, being based on a valgus stress while flexing the limb and maintaining the foot internally rotated (Jacob, et al., 1987). In fact, surgeons who carry out PS test, usually affirm to sense a sort of 'clunk' while testing a pathologic knee; this qualitative evaluation is extremely difficult to quantitatively define and thus quantitatively differentiate an ACL-injured limb with respect to a healthy one is a not simple task.

During the last decades qualitative methods and several devices have been suggested to standardize the level of ACL injuries correlated to joint dynamic instabilities, but they revealed a quite complex and bulky set-up for an outpatient's clinical use or allowed only a partial assessment of joint laxity (Lopomo, et al., Kuroda, et al., Dierman, et al., Labbe, et al., 2008; Amis, et al., 2008, 2005; Mushal, et al., 2007; Csintalan, et al., 2006; Bleday, et al., 1998).

For these reasons a method which can provide a reliable diagnosis of dynamic knee instability with fewer and simpler measurements, can surely be of benefit for clinical scope.

As reported in literature (Colombet, et al.; Hoshino, et al., 2007), one of the most interesting parameter to investigate can be the acceleration reached by the joint during the PS manoeuvres itself, representing a possible correlation with the alteration in the fluidity of the movement due to the presence of PS phenomenon. The main objective of this study was therefore to develop and validate a methodology able to automatically quantify the PS test, giving also a clinical reliability to the analysis. In particular 3D acceleration was recorded during PS manoeuvres by means of a commercial triaxial accelerometer and the output signal was automatically analysed in order to filter the noisy part and to automatically extract the clinical information related to the PS test.

2 METHODS

We conducted the presented study on 35 consecutive patients, with acute or chronic ACL injury, that underwent ACL reconstruction between August 2008 and August 2009 in our Institute. The performed experimental procedure was established on the first 15 patients that were not included in this study. The applied clinical protocol was approved by the Institutional Review Board of the Institute.

The system used to acquire 3D joint acceleration during PS test was a triaxial accelerometer sensor (Inertis-link, Microstrain Inc., Williston, VT, USA); the device was connected wirelessly to a dedicated laptop on which, by means of a simple interface, the operator was able to monitor in real-time the patterns of acceleration and to acquire the 3D data. The sensor was not-invasively mounted on the skin of the patient and securely fixed by means of a specific strap between the lateral aspect of anterior tuberosity and Gerdy's tubercle, in order to achieve an optimal stability. The PS test was repeated 3 times by an expert and a novice orthopaedic surgeon. Each surgeon realized test repetitions, both on pathologic limb and healthy one. The test was repeated by the expert surgeon also before and after the general or regional anaesthesia.

We used the module of 3D acceleration measured by the sensor, as the most significant parameter to be analysed during the PS manoeuvre. In particular we proceeded to extract maximum (MAX) and minimum (min) value of the acceleration, their difference (Diff) and the first derivative of acceleration (in physics indicated as "jerk") as an indication of the smoothness of the performed movement. The processed signal and the parameters chosen for the diagnosis are reported in figure 1.
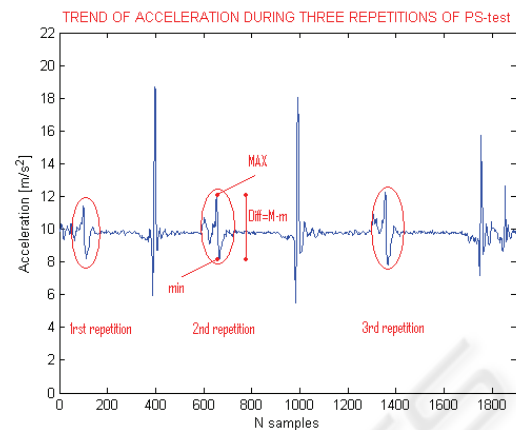

Figure 1: Typical trend of acceleration during the three repetitions of pivot-shift test. "MAX", "min" and "Diff" are the parameters, besides jerk, evaluated in this study.

The automatic data processing is based on the calculation of Pearson's correlation coefficient by means of overlapping a specific template and the signal recorded. The template was defined as the average trend manually identifying the repetitions obtained by the first 35 patients, that were thus used as reference sample. As known, Pearson's correlation coefficient (R, with $-1 \leq R \leq 1$) generally indicates the strength and direction of a linear relationship between two variables; in our case the first variable is the template and the second is the corresponding window on the processed signal, so that R can be helpful to recognize the presence of a trend similar to what represented in the template. For instance, supposing to have two variables X and Y, with means $\overline{X}$ and $\overline{Y}$ respectively and standard deviation Sx and Sy, n is the number of samples of X and Y, the correlation R is computed as shown in the equation 1:

$$R = \frac{1}{n-1} \sum_{i=1}^{n} \left(\frac{Xi - \overline{X}}{Sx} \right) \left(\frac{Yi - \overline{Y}}{Sy} \right)$$

Equation 1: Calculation of Pearson's correlation coefficient (R).

During each iteration of the algorithm, the evaluation took into account a shear of signal with the same length of the template sample-by-sample until the last one.

A threshold for the value of coefficient R over that the algorithm recognize the PS repetition was manually fixed to 0.7, on the basis of the reference sample. Moreover in order to increase the reliability of the algorithm specific thresholds were defined relative to the clinical parameters chosen for the

diagnosis, thus avoiding clinically meaningless false identifications. In particular "MAX" must be ≤ 14.3 m/s^2, "min" must be ≥ 6.5 m/s^2 and "Diff" must be ≥ 2.2 m/s^2. In figure 2 is reported the template used for the automatic data processing while flowing along the signal automatically recognizes the PS repetitions.
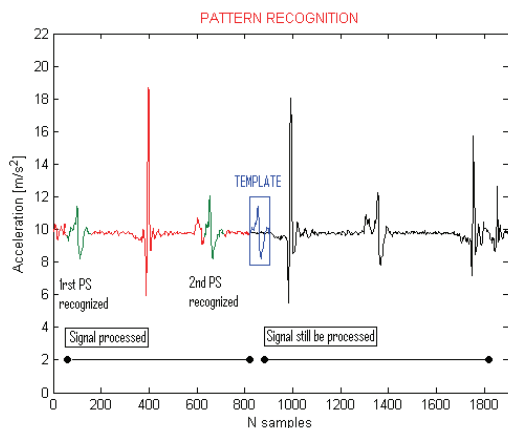

Figure 2: The automatic analysis. In blue, inside the frame, is represented the window chosen as template which is flowing along the signal, in green the first end the second repetition of PS recognized thanks to an high Pearson's correlation coefficient associated with the template ($R \geq 0.7$), while in red is underlined the shear of signal already processed and in black the signal which is going under processing.

The automatic method identification performance was evaluated in terms of percentage sensitivity, specificity and accuracy, applying the algorithm on the entire set.

3 RESULTS

Using Pearson's correlation coefficient, together with the other mentioned thresholds, provided us a classification accuracy around 96.7%. The classification performance measures are presented in table 1.

Table 1: Classification performance on the test for the method used for the automatic recognition of the PS test.

	% VALUE
Sensitivity	81.9
Specificity	99.3
Accuracy	96.7

For the evaluation of this classification a direct method was used, i.e. the training set was classified with a classifier built using the training set data itself.

4 CONCLUSIONS

The goal of our study was to develop a methodology able to provide a quantification of the PS test. We defined therefore a method to easily analyse the acceleration signal during PS test with the goal to achieve non-invasive, portable and user-friendly tool able to provide a quantitative and complete diagnose of ACL deficient knee. This method used a predefined template and the computation of Pearson's correlation coefficient between this prototypical pattern and the signal under processing. In literature there are different methods dedicated to pattern recognition, even if they are more specific and require a major computational load.

Being acceleration PS event quite readily recognizable and identifiable from the remaining parts of signal, we privileged the easiness of computation, in order to apply the automatic recognition also to real-time applications.

A limitation of this study was due to the template form; its simple and linear waveform is quite easy to generate also by a mistakenly moved tool. This conditions could generate false positive (FP) cases. On the other hand a sudden motion during the test could falsify the typical trend of the signal, provoking false negative (FN) cases. Moreover the coupled loads applied by the surgeon were not quantitatively controlled and the considered parameters could be strongly affected.

We are convinced that provide to the surgeons an accurate description of the movement to perform in order to realize the pivot-shift test always in the same way and limit the movements of the tested limb, usually provoked by the operator to relax the limb, could improve the performance of the model regarding false-positive and false-negative.

Further analyses imply to verify the skill, in terms of sensitivity, specificity and accuracy, of the clinical method purposed to discern between pathologic and healthy knee.

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