Spike the PCHA! Overuse injury of the Posterior Circumflex Humeral Artery in elite volleyball
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CHAPTER 4

Test-retest reliability of the SPI-Questionnaire
to detect symptoms of digital ischemia in elite
volleyball players

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Submitted
ABSTRACT

The Shoulder PCHA pathology and digital Ischemia – Questionnaire (SPI-Q) has been developed to enable periodic surveillance of elite volleyball players, who are at risk for digital ischemia. Prior to implementation, assessing reliability is mandatory. Therefore, the test-retest reliability of the SPI-Q was assessed among the population at risk.

A questionnaire survey was performed with a two-week interval among 65 elite male volleyball players assessing symptoms of cold, pale and blue digits in the dominant hand during or after practice or competition using a 4-point Likert scale (never, sometimes, often, always). Kappa (κ), percentage of agreement (POA), and Intra-class Correlation Coefficient (ICC) were calculated for individual symptoms, severity of symptoms, and to distinguish symptomatic and asymptomatic players.

For the individual symptoms, κ ranged from ‘poor’ (0.25) to ‘good’ (0.63), and POA ranged from ‘moderate’ (78%) to ‘good’ (97%). To classify symptomatic players, the SPI-Q showed ‘good’ reliability (κ=0.83; 95%CI 0.69-0.97) and the same was true for the severity of symptoms (ICC=0.82; 95%CI 0.72–0.88). Since the SPI-Q is reliable, it can be used for periodic surveillance to detect and monitor elite volleyball players with symptoms of digital ischemia in time.
INTRODUCTION

Elite volleyball players are at risk for digital ischemia, which may be due to arterial emboli originating from an aneurysmal and thrombosed posterior circumflex humeral artery (PCHA) in the dominant shoulder, among other causes. Irrespective of the cause, creating awareness and monitoring these seemingly innocuous symptoms to detect onset and worsening is important since these athletes are at risk of emboli in the dominant hand, possibly resulting in irreversible tissue damage, and ultimately necrosis and finger loss if trivialized.

For this purpose, the Shoulder PCHA pathology and digital Ischemia – Questionnaire (SPI-Q) was developed using reports of volleyball players with confirmed digital ischemia combined with medical literature on symptoms associated with digital ischemia. Currently, the most commonly used instruments in patients with peripheral arterial disease, such as chronic critical lower limb ischemia, include generic quality of life (QoL) questionnaires, such as the Short Form-36 (SF-36) and disease-specific QoL questionnaires, such as the Vascular Quality of Life questionnaire (VascuQol). However, to our knowledge, no disease-specific questionnaires exist for symptoms of digital ischemia in the upper limb.

Before the SPI-Q can be used for periodic surveillance, its measurement properties should be tested. Therefore, the purpose of this study is to assess the test-retest reliability of the SPI-Q for detection of symptoms of digital ischemia in the population at risk: elite male volleyball players.

METHODS

Study design
A prospective cohort study was performed among elite male volleyball players in the Netherlands. Official approval of this study was waived by the Institutional Review Board (IRB) of our academic hospital.

Participant selection
A power analysis in nQuery advisor 7.0 (Statistical Solutions Ltd, 2007) showed that 62 participants were needed with kappa=0.7, precision=0.15 and a one-sided confidence level of α=0.05. The inclusion criteria were: (1) being an elite male indoor volleyball player active in the Dutch national top or second league in the seasons 2013-2014; and (2) written informed consent. To secure sufficient variety in players with and without symptoms of digital ischemia, 84 volleyball players who reported at least one symptom of cold, blue or pale digits in the dominant hand during or directly after practice or
competition were selected from a previous study, and supplemented with volleyball players who reported no symptoms (n=22).

**Study protocol**
An electronic questionnaire was sent through a digital email link with a two-week interval between test (t=1) and retest (t=2). This time interval was chosen to prevent both recall bias and change in health condition/symptoms. To assure no bias was caused by a change in the prevalence of symptoms between t=1 and t=2, for each of the six symptoms the following question and answer categories were formulated in the retest questionnaire: ‘Does this symptom occur less often, equally often or more often than 14 days ago when you filled in the first questionnaire?’ If a participant answered one of these six questions with ‘less often’ or ‘more often’, the participant was excluded from the analysis.

**Questionnaire content**
The SPI-Q was developed using reports of volleyball players with confirmed digital ischemia, based on evidence from the medical literature, and comprises two general domains: A) characteristics of the individual player, such as age and total years playing volleyball; and B) those concerning symptoms of digital ischemia in the dominant hand, like cold, blue or pale digits, occurring both during and directly after practice as well as in competition (Table 1). A 4-point Likert scale was used for the answer categories of the questions on symptoms: ‘never’, ‘sometimes’, ‘often’, ‘always’. The complete questionnaire used in the study is included in Appendix A.

**Data analyses**
The data from the questionnaires were entered in SPSS (version 21.0, 2012, SPSS Inc.) and randomly checked for correct entry. The mean, standard deviation, maximum and minimum of age, body weight, body height, total years playing volleyball, and total hours volleyball played in the last 14 days were reported for the group as a whole.

Test-retest reliability was calculated and expressed in three ways:
1. Linear weighted kappa ($\kappa$) was calculated for each of the individual symptoms of digital ischemia, i.e. cold, blue or pale digits during and after practice and competition. $\kappa$ is the recommended parameter for the estimation of reliability for categorical data, and was calculated using a website. The linear weights for the weighting matrix were calculated using the following formula: $1 - ((i-j) / (k-1))$, where ‘i’ is the category rated in test 1, ‘j’ the category rated in test 2 and ‘k’ the total number of categories. To reflect sampling error, the confidence interval (CI) of the linear weighted $\kappa$ was also calculated. The following decision criterion was formulated for the interpretation of the values of $\kappa$: >0.60 = ‘good’, 0.41-0.60 = ‘moderate’, and <=0.40 = ‘poor’. To assess the dependence of $\kappa$ from the
distribution of data, the percentage of agreement (POA) of the measurements classified in the same categories in the test and retest questionnaires was calculated for each of the individual symptoms of digital ischemia, i.e. cold, blue or pale digits during and after practice and competition. The following criterion was formulated for the interpretation of the values of POA: >90% = ‘good’, 70-90% = ‘moderate’, and <70% = ‘poor’. The unweighted κ was calculated for the reliability of the combined question: is a volleyball player symptomatic? To do so, the answers to the individual symptoms of digital ischemia, i.e. cold, blue or pale digits during and after practice and competition were combined in order to label a volleyball player as symptomatic or asymptomatic. The case definition of symptomatic was: a volleyball player who reported one or more of the symptoms cold or blue or pale digits during or after volleyball. Volleyball players without these symptoms were defined as asymptomatic. The values of the κ were interpreted in the same manner as described above for the linear weighted κ. Intra-class correlation coefficient (ICC), model single measure, two-way random, and absolute agreement, was calculated to express the reliability of the sum-score to determine the severity of symptoms of digital ischemia, i.e. cold, blue
or pale digits during and after practice and competition. Points were given to all four answer categories: never (0 points), sometimes (1 point), often (2 points) and always (3 points), resulting in a maximum score of 18 points. The following decision criteria were formulated for the interpretation of the values of ICC: >0.75 = ‘good’, 0.50-0.75 = ‘moderate’, and < 0.50 = ‘poor’. To put the ICC in the context of the data from which it was derived, the standard error of measurement (SEM), the smallest detectable change (SDC), and the limits of agreement (Loa) were also calculated, with smaller SEMs and SDCs or Loas indicating less measurement error. The following two formulas were used: SD_{difference} = √2 x SEM_{consistency} and Loa = SDC = mean_{difference} ± 1.96 x SD_{difference}.

RESULTS

Participants
From March to May 2015, a total of 106 volleyball players were invited to participate, of whom 73 agreed to participate and 71 of these 73 completed the questionnaire both times, a response rate of 97%. Six volleyball players were excluded because they reported a change in the frequency of symptoms in the two weeks between completing both questionnaires: five volleyball players reported symptoms less often, and one reported symptoms more often. These participants were advised about follow-up. As a result, 65 volleyball players, completing both questionnaires in 15±4 days (range 7-31 days), were included (Figure 1). On average, volleyball players were 27±5 years old (range: 19-42

Figure 1 Flow chart of participant inclusion
years), had a body height of 195±7 centimetres (cm) (range: 175-207 cm), and had been playing volleyball for 17±6 years in total (range 6-33 years) and 15±8 hours in the last 14 days (range 0-30 hours).

**Prevalence of symptoms of digital ischemia**

Cold and pale digits during practice or competition were most prevalent with percentages ranging from 20% to 26%. Blue digits directly after playing volleyball were rarely reported (3%) and none of the volleyball players reported a symptom as always being present (Table 2). During test (t=1) and retest (t=2), respectively 37% (n=24) and 35% (n=23) of surveyed volleyball players reported at least one of the symptoms of cold or blue or pale during or after volleyball.

**Test-retest reliability**

*Individual symptoms of digital ischemia*

Linear weighted κ for the individual symptoms of digital ischemia ranged from ‘poor’ (0.25) for pale digits after practice or competition to ‘good’ for cold digits during practice or competition (0.63). The POA for these individual symptoms ranged from ‘moderate’ (78%) for pale digits during competition to ‘good’ (97%) for blue digits after competition (Table 3).

**Table 2** Prevalence of symptoms (% and number) of digital ischemia during or directly after practice or competition in the dominant hand in elite male volleyball players during test (t=1) and retest (t=2) (n=65)

<table>
<thead>
<tr>
<th>Symptom</th>
<th>During practice or competition</th>
<th>During practice or competition</th>
<th>Directly after practice or competition</th>
<th>Directly after practice or competition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Never % (n)</td>
<td>Sometimes % (n)</td>
<td>Often % (n)</td>
<td>Always Symptomatic % (n)</td>
</tr>
<tr>
<td>Cold t= 1</td>
<td>80 (52)</td>
<td>15 (10)</td>
<td>5 (3)</td>
<td>0 (13)</td>
</tr>
<tr>
<td>Cold t= 2</td>
<td>74 (48)</td>
<td>20 (13)</td>
<td>6 (4)</td>
<td>0 (17)</td>
</tr>
<tr>
<td>Blue t= 1</td>
<td>92 (60)</td>
<td>6 (4)</td>
<td>2 (1)</td>
<td>0 (5)</td>
</tr>
<tr>
<td>Blue t= 2</td>
<td>90 (59)</td>
<td>8 (5)</td>
<td>2 (1)</td>
<td>0 (6)</td>
</tr>
<tr>
<td>Pale t= 1</td>
<td>75 (49)</td>
<td>22 (14)</td>
<td>3 (2)</td>
<td>0 (16)</td>
</tr>
<tr>
<td>Pale t= 2</td>
<td>78 (51)</td>
<td>19 (12)</td>
<td>3 (2)</td>
<td>0 (14)</td>
</tr>
</tbody>
</table>
Symptomatic for digital ischemia
The unweighted κ calculated for the combined question to determine whether a volleyball player is symptomatic based on one or more symptoms of digital ischemia was ‘good’ (0.83) (Table 4).

Severity of symptoms of digital ischemia
The ICC calculated for the sum-score to determine the severity of symptoms of digital ischemia showed ‘good’ agreement (0.82; 95%CI 0.72–0.88). The SEM was 0.72, the MDC was 2.00, and the Loas were -0.15 ± 2.00 (-2.15-1.84) (Table 5).

Table 3 Prevalence in test (t=1) and retest (t=2), percentage of agreement (POA), linear weighted kappa (κ), and 95%CI of symptoms of digital ischemia during and after practice and competition among elite male indoor volleyball players

<table>
<thead>
<tr>
<th>N</th>
<th>Prevalence during t=1 (%)</th>
<th>Prevalence during t=2 (%)</th>
<th>POA (%)</th>
<th>Linear weighted κ</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold digits during</td>
<td>65</td>
<td>20</td>
<td>26</td>
<td>85</td>
<td>0.63</td>
</tr>
<tr>
<td>Cold digits after</td>
<td>65</td>
<td>9</td>
<td>14</td>
<td>91</td>
<td>0.58</td>
</tr>
<tr>
<td>Blue digits during</td>
<td>65</td>
<td>8</td>
<td>9</td>
<td>92</td>
<td>0.58</td>
</tr>
<tr>
<td>Blue digits after</td>
<td>65</td>
<td>3</td>
<td>3</td>
<td>97</td>
<td>0.48</td>
</tr>
<tr>
<td>Pale digits during</td>
<td>65</td>
<td>25</td>
<td>22</td>
<td>78</td>
<td>0.48</td>
</tr>
<tr>
<td>Pale digits after</td>
<td>65</td>
<td>11</td>
<td>14</td>
<td>83</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Table 4 Prevalence in test (t=1) and retest (t=2), percentage of agreement (POA), unweighted kappa (κ) and 95%CI of the combined question: is a volleyball player symptomatic?

<table>
<thead>
<tr>
<th>n</th>
<th>Prevalence during t=1 (%)</th>
<th>Prevalence during t=2 (%)</th>
<th>POA (%)</th>
<th>Unweighted κ</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined question: is a volleyball player symptomatic? (yes/no)</td>
<td>65</td>
<td>37</td>
<td>35</td>
<td>92</td>
<td>0.83</td>
</tr>
</tbody>
</table>
DISCUSSION

This study shows that the SPI-Q is a reliable questionnaire for detecting cold and blue digits, to distinguish symptomatic volleyball players from asymptomatic ones based on one or more symptoms, and for grading the severity of symptoms. Only assessing pale digits showed ‘poor’ to ‘moderate’ results.

This is the first study to provide a reliable tool that can assess symptoms of digital ischemia in elite volleyball players: the population at risk. To our knowledge, no comparable questionnaires have been developed, nor tested, for upper limb ischemia in this or any other population of elite overhead athletes at risk, such as baseball pitchers.27 For lower limb ischemia, questionnaires like the VascuQol have been developed and extensively tested for their measurement properties.22,30 However, these questionnaires are mostly used for QoL outcomes of patients diagnosed with – or treated for – chronic critical lower limb ischemia74, while the SPI-Q has been developed for targeted detection and monitoring of symptoms of digital ischemia in healthy elite overhead athletes.

To classify symptomatic players based on one or more symptoms, the SPI-Q showed ‘good’ reliability. This indicates that the SPI-Q is a reliable instrument for detecting symptomatic volleyball players. Furthermore, ‘good’ reliability was found for the sum-score to determine the severity of symptoms of digital ischemia reported in the SPI-Q. For the SPI-Q sum-score, the MDC and Loa were calculated to assess which changes can be detected outside the measurement error. An MDC of 2.00 (rounded) suggests that a change of 2 points or more can be detected by the SPI-Q questionnaire as real change on a scale from 0-18, suggesting acceptable measurement error. However, what the exact magnitude of the real change should be to be considered as a clinically important change or minimally important change (MIC) is to be determined in future research regarding responsiveness and validity.123 In addition, the outcomes for the individual symptoms of digital ischemia were diverse: the linear weighted κ ranged from 0.25 to 0.63 (‘poor’ to ‘good’ reliability), and the POA values ranged from 78% to 97% (‘moderate’ to ‘good’), making these questions seem less suited for detecting elite male volleyball players with symptoms when used individually. This seems especially true for detecting pale digits.
However, the big difference between the linear weighted $k$ values and POA implies high agreement by chance and might have resulted from the homogeneity of symptoms across the different answer categories.\textsuperscript{112,124}

**Strengths and weaknesses**
A strength of this study was the power analysis via nQuery advisor 7.0 and the inclusion of 65 volleyball players, since a sample size of at least 62 was considered adequate. Another strength is that all symptomatic players from a previous study were selected to secure sufficient variety in the main outcome ‘presence and absence of symptoms’. Little variety would have caused a poor level of reliability, as found in other studies.\textsuperscript{35} A weakness of the SPI-Q is that none of the participants reported experiencing one of the symptoms as ‘always’. Therefore, one might consider modifying the answer categories ‘often’ and ‘always’ to ‘regularly’ and ‘often’, respectively. Of course, the effects of these changes on reliability of reporting of individual symptoms should be assessed in future studies.

**Clinical implications**
The self-reported prevalence of cold or blue or pale digits in the dominant hand during or immediately after practice or competition is 38\% among international world-class male and female beach volleyball players, and 31\% among elite male indoor volleyball players.\textsuperscript{88,89} These symptoms are associated with digital ischemia, which can be caused by a wide variety of vascular and non-vascular pathologies\textsuperscript{90}, including arterial emboli originating from an aneurysmal and thrombosed PCHA in the dominant shoulder.\textsuperscript{89} Volleyball players with confirmed digital ischemia present themselves late in disease with severely disabling coldness, discolouration, pain and paresthesia in the dominant hand.\textsuperscript{93} Active surveillance enables identification of apparently innocuous symptoms, like coldness and discolouration, at an early stage, and might prevent thromboembolic complications, irreversible tissue damage, and possibly surgical ligation of the PCHA.\textsuperscript{89} The responsiveness of the SPI-Q needs to be determined in future studies.

The current study has proven the SPI-Q to be reliable for detecting elite male indoor volleyball players with symptoms of digital ischemia, and for grading the severity of these symptoms. Therefore, we can recommend using the SPI-Q for periodic surveillance to detect and monitor elite volleyball players with symptoms of digital ischemia in time.
APPENDIX A – SPI-Q QUESTIONNAIRE

Domain A: personal and sports characteristics of the participants
1. What is your age?
2. What is your body height?
3. What is your body weight?
4. How many years in total have you played volleyball?
5. How many hours in total have you played volleyball in the last 14 days? (training and competition)

Domain B: symptoms associated with digital ischemia
6. How often do you suffer from one or more cold fingers in your dominant hand during practice or competition?
   - No, never
   - Yes, sometimes
   - Yes, often
   - Yes, always

7. How often do you suffer from one or more cold fingers in your dominant hand directly after practice or competition?
   - No, never
   - Yes, sometimes
   - Yes, often
   - Yes, always

8. How often do you suffer from one or more blue fingers in your dominant hand during practice or competition?
   - No, never
   - Yes, sometimes
   - Yes, often
   - Yes, always

9. How often do you suffer from one or more blue fingers in your dominant hand directly after practice or competition?
   - No, never
   - Yes, sometimes
   - Yes, often
   - Yes, always

10. How often do you suffer from one or more pale fingers in your dominant hand during practice or competition?
    - No, never
    - Yes, sometimes
    - Yes, often
    - Yes, always

11. How often do you suffer from one or more pale fingers in your dominant hand directly after practice or competition?
    - No, never
    - Yes, sometimes
    - Yes, often
    - Yes, always