CHAPTER 2

LITERATURE REVIEW

2.1. INTRODUCTION

In the previous chapter an overview of the broader contextual background to the research study was given. This included the research problem, research and investigative questions, the process that was followed, an overview of the structure of this document, and a chapter and content analysis. In this chapter an overview of the literature research will be given. The first section of the chapter deals with the research methodology. This is followed with a section on CPCS. In the third section fascia (collagen tissue) and myofascial links are covered, as well as a review of biomechanical factors linked to CPCS by this research. Section four deals with an extended literature research which was done towards the end of the exploratory phase of the research project.

2.2. RESEARCH METHODOLOGY

2.2.1. An introduction to qualitative research

In this section an overview of the literature research on research methodology will be given, with specific reference to qualitative research methodologies.

The major divide in the research world is between research in the physical and natural world and research in the social world (Watkins, 2006). Although research approaches are not unique to any of these, one does find that research in the first category is normally dominated by quantitative approaches. This is largely due to the rich wealth of theoretical knowledge that has been developed and underpins research in this area. Research in the natural and physical world is thus normally based on quantitative experimentation and research that does not conform to this framework is often frowned upon.

One however encounters situations where the current theoretical frameworks prove to be inadequate in terms of its ability to provide basic causal relationships between the variables under investigation (Smart & Doody, 2003; Yin, 2003). In such situations the researcher is thus forced to revert to exploratory research in order to develop new or modified theoretical concepts to predict the behavioural characteristics of variables. In such situations, the researcher is forced to the application of qualitative research methodological approaches and associated research techniques to create the necessary fundamental understanding of the variables under consideration.

The focus of this section of the literature study is thus largely on qualitative research techniques and approaches, as well as the transition from relatively unstructured exploratory research, to the validation of new theory by means of explanatory research techniques. It is assumed that the reader is fairly conversant with quantitative research paradigms, and these aspects will thus not be covered in any depth in the literature review. Where appropriate, references will be provided with the actual designs of such quantitative research applications.

As stated in the introductory chapter, the research is in certain respects unique due to a number of considerations. These include:

- The fact that the research is dealing with a subject topic from the medical sciences where research are normally subject to classical experimentation.
- The research project deals with both explorative as well as explanatory research, as the current theoretical framework fails to provide adequate explanation to the initiation as well as behavioural issues associated with the condition.
- The research project deals with both qualitative as well as quantitative research paradigms.

The objectives of the section on research methodology were thus:

- To provide the researcher with the necessary contextual background for the selection of an appropriate research methodological approach for the research project.
- To provide the researcher with an overview of the key concepts associated with the selected research methodology.

- To provide the researcher with the necessary contextual background in order to generate the necessary research designs overview of the research design.
- To provide the researcher with an overview of the criteria for the assessment of the quality of the design.

As stated, the research deals with both exploratory as well as explanatory issues that falls in the domain of qualitative research. It also deals with selective experimental research on biomechanical measures which is used to explore the validity of certain conclusions drawn from new theoretical model developed as a result of the research. The utilization of such diverse research paradigms are from an epistemological perspective, classified as "mixed methodologies". The literature review will be introduced by the discussion of the concept of "Mixed Methodologies" (Watkins, 2006) as embodied in this thesis.

2.2.2. Mixed methodologies

The utilisation of mixed methods research designs have grown considerably since the late 1970's (Hanson *et al.*, 2005; Christ, 2007). The obvious advantage of a multi-method approach developed by Campbell & Fiske during 1959, according to Hanson *et al.* (2005) is that it eliminates method bias in the research which one would assume increases the generalisation of research findings.

With regard to the philosophical base of the research paradigm general consensus is that it is based on pragmatism (Tashakkori & Teddlie, 2003). In addition to the argument that the *position* as established by triangulation would be more exact, these authors argue that the research question is the prime objective. With this pragmatic perspective, any method which could reveal answers to this question could and should be used.

According to Watkins (2006:44) who cites Easterby-Smith *et al.* (1996:133-134), the use of multiple, but independent measures is known as triangulation, of which four categories exists, namely, *theoretical triangulation, data triangulation, investigator triangulation* and *methodological triangulation*. Within the ambit of this research only the latter applies. According to Yin (1994) the concept of triangulation in research methodology originated from the natural sciences where triangulation refers to the definition of a point in a geometric space by means of the intersection of three vectors. One or two such vectors are insufficient whilst a fourth would be redundant. This concept is incorrectly attributed by some (Hanson *et al.*, 2005) to military naval sciences who also used the principle to establish the exact location of an object at sea.

The key question is thus to direct the same question to different sources of evidence.

Methodological triangulation

Methodological triangulation refers to research where both quantitative as well as qualitative research approaches are used for data collection. This culminates in diverse data collection techniques which can be juxtaposed with regard to the answering of research questions (Watkins, 2006). Within the context of this research both multiple case studies and experimentation are used for data collection. In the following section pertinent aspects associated with case study research will be reviewed.

2.2.3. Case study research methodology

Watkins (2006: 38) drawing descriptions from Hussey & Hussey (1997), Leedy and Ormrod (2001) and Remenyi *et al.* (2002); define case study research as follows:

- **Case study research**

  "Primarily falling within the phenomenological (qualitative) paradigm, case study research can equally be applied within the context of the positivistic (quantitative) paradigm. Case study research represents an empirical enquiry that investigates a contemporary phenomenon within a real life context, when the boundaries between phenomenon and context are not clearly evident, and in which multiple sources of evidence are used. It is particularly valuable in answering who, why and how questions in research."

Case study research is often used in exploratory research (Boos & Brownie, 1992; Hussey & Hussey, 1997 as cited by Scholz & Tietje, 2002). The latter identify classes of case studies, namely *"Descriptive case studies"*, *"Illustrative case studies"*, *"Experimental or Exploratory case studies"* and *Explanatory case studies"*. Within the ambit of this thesis only *"Experimental* or *Exploratory"* and *"Explanatory"* case studies are used. The term "*Exploratory Case Study*" is preferred and will be used throughout this thesis.

- **Exploratory case studies**

Exploratory case studies help to gain insight into the structure of a phenomenon in order to develop hypothesis, models or theory (Scholz & Tietje, 2002). According to them the research design and data collection methods are usually not specified in advance due to the exploratory nature of the research process.

- **Explanatory case studies**

Explanatory case studies can also serve to test cause-and-effect relationships (Scholz & Tietje, 2002; Payne & Williams, 2005). Henning *et al*. (2004) citing Stake (1995) highlights that in a case study the main assumption is that the phenomenon is investigated as a "*bounded system"*. This concept of a *"bounded system"*, proved to be significant in terms of the definition of CPCS during the latter phases of the research.

2.2.3.1. General approach to case study design

According to Yin (2003:19-20), a research design can be defined as:

> *"... the logical sequence that connects the empirical data to a study's initial research question and ultimately, to its conclusions. Colloquially, a research design is an action plan from getting from here to there, where here may be defined as the initial set of questions to be answered, and there is some set of conclusions about these questions*".

Yin (2003: 20) also quotes Nachimias & Nachimias (1992:77-78) who defines it as "… a *logical model of proof that allows the researcher to draw inference concerning causal relations among variables under investigation"*.

2.2.3.2. Components of research design

Yin (2003) identifies five components of research designs that are especially important, namely: a *study's questions*; its *propositions*, if any; its *units of analysis*; the *logic linking the data to the propositions*; and the *criteria for interpreting the findings*. These components will be briefly reviewed.

- **The study's question**

The study's questions provide guidance as to what the most appropriate research strategy would be. The case study strategy is most likely to be appropriate for *how* and *why* questions.

- **The study's proposition**

The proposition directs attention to something that should be addressed. "… *only if you are forced to (able to) state some proposition will you move into the right direction"* (Yin, 2003: 22).

- **The unit of analysis**

> **"***The main unit of analysis is likely to be at the level being addressed by the main study questions. … As a general guide, your tentative definition of the unit of analysis (and therefore the case) is related to the way you have defined your initial research question"* (Yin, 2003: 22 - 23).

According to Yin (2003) the selection of the appropriate unit of analysis occurs when one accurately specifies the primary research question. If the question does not favour one unit of analysis above another, the research question is in all probability too vague. Typical units of analysis according to Hussey & Hussey (1997) could include:

- ***An individual***

A person is a popular unit of analysis.

- ***An event***

An event is a reference to a particular incident that could trigger a certain response.

- ***An object***

An object is a commodity such as a product, a service or a process.

- ***A body of individuals***

A body of individuals includes groups of people.

- ***A relationship***

A relationship refers to the relationship between two or more individuals or bodies.

According to Yin (2003), the design should also tell you what is to be done after the data have been collected – as indicated by the *logic that links the data to proposition* and the *criteria for interpreting findings*. These are discussed in the following paragraphs.

- **Linking data to propositions**

One of the most precise examples quoted by Yin (2003) is that of linking treatments with patients in psychological experiments. This process has direct bearing on the research in question.

- **Criteria for interpreting a study's findings**

Yin (2003) suggests that different patterns are sufficiently contrasted in terms of rival propositions. Hussy & Hussey (1997) identify a further refinement to the above by addressing the attributes of the unit of analysis.

- **Identification of variables**

For a *"qualitative phenomenon"* they refer to a non-numerical attribute of an object such as hair colour, job grades, or gender. A *"quantitative variable"* refers to a numerical attribute of an individual or an object, such as age, height or weight. A positivistic study would in addition call for the classification of such variables into dependent and independent variables. In this respect an independent variable is the variable that can be manipulated in order to predict behaviour of the dependent variable.

According to Hussey & Hussey (1997) it is important to note that irrespective of the research paradigm (*positivistic* or *phenomenological*), one will always find a combination of qualitative and quantitative inputs into the data collection process. The following data collection techniques are adapted from their work.

- **Data collection method**

The following methods were considered relevant to the research project:

- ***Critical incident technique***

This technique focuses on an observable activity, where the intended purpose is clear and the effect appears to be logical.

- ***Interviews***

Represents a method of collecting data where the subjects are asked questions in order to establish their experience base. A positivistic approach suggests structured questions where the respondent answers from a number of presentiment outcomes. With a phenomenological approach unstructured *"open-ended questions"* where the subject is enticed to give his own opinion, would be more appropriate.

- ***Participant Observation***

Is a method of collecting data where the researcher is fully involved with the participants and the phenomena being investigated.

2.2.3.3. The role of theory in design

Yin (2003) proclaims that theory development as part of the design phase is essential. The complete research design embodies a "theory" of what is being studied. The goal is to have some theoretical basis for formulating theoretical propositions, i.e. *"a story about why acts, events, structure, and thoughts occur"*.

2.2.3.4. Criteria for judging the quality of research designs

According to Yin (2003) four tests are commonly used to establish the quality of any empirical social research. Due to the commonality of the research approaches one could argue the relevance of these for any qualitative research. The tactics associated with each of these are represented in Table 2.1 (Yin, 2003: 34).

Table 2.1: Tactics for ensuring quality research designs

Test	Case Study Tactic	Research Phase
Construct Validity	➢ Use multiple sources of evidence ➢ Establish a chain of evidence ➢ Key informant reviewing draft case study report	➢ Data collection ➢ Data collection ➢ Composition
Internal Validity	➢ Pattern matching ➢ Explanation building ➢ Addressing rival explanations ➢ Arguments based on logic models	➢ Data analysis ➢ Data analysis ➢ Data analysis ➢ Data analysis
External Validity	➢ Use of theory ➢ Use of replication logic	➢ Research design ➢ Research design
Reliability	➢ Use of case study protocol ➢ Develop a case study database	➢ Research design* ➢ Data collection

(Yin (2003) reflects this issue as occurring in the data collection phase. Olivier (2004:75) presents a persuasive argument for addressing it during the design phase)*

- **Reliability**

Reliability demonstrates that the operation of a study, such as the data collection procedure, can be repeated with the same results.

- **Construct validity**

Construct validity establishes correct operational measures for the concepts under investigation.

- **Internal validity (explanatory or causal studies only)**

Internal validity refers to establishing causal relationships whereby certain conditions are shown to lead to other conditions as distinguished from spurious relationships.

  - **Pattern matching or relying on theoretical propositions**

A promising approach is that of Campbell & Fiske (1959) whereby several pieces of information from the same case may be related to some theoretical proposition. According to Yin (2003) the preferred strategy is to follow the theoretical propositions that led to the case study. Theoretical propositions about causal relations can be very useful in guiding case study analysis.

  - **Explanation building**

Explanation building is considered by Yin (2003:120) as a special case of pattern matching. The goal is to analyse the case data and to build an explanation about the case. *"To explain a phenomenon is to stipulate a presumed set of causal links about it"*. In most case studies explanation occurs in a narrative form and according to Yin the better case studies are those where the explanations have reflected some *"significant theoretical propositions"*.

  - **Addressing rival explanations**

Rival explanations could be based on for example current existing theoretical frameworks against which the new theoretical concepts could be compared (Yin, 2003). Yin reflects on a brief description of the different rival explanations from one of his earlier works (Yin, 2003). An adapted table of examples are provided in Table 2.2.

Table 2.2: Different kinds of rival explanations

Type of Rival	Description or example of cause
Craft rivals:	
The Null Hypothesis	The observation is the result of chance observation
Threats to Validity	Instability; testing
Investigator Bias	Experimenter effect
Real-life rivals:	
Direct rival	Another intervention than the target intervention
Commingled rival	Other interventions plus the target intervention
Implementation rival	Implementation process rather than targeted intervention
Rival theory	A different theory explains results

- **Using logic models**

"*The use of logic models as an analytic technique consists of matching empirical observed events to theoretical predicted events*" (Yin, 2003: 127). The logic models are distinguished from pattern matching in the sense that it consists of sequential stages where outcomes are differentiated in terms of *immediate*, *intermediate* and *ultimate* outcomes. The logic models thus have a "*programme logic*" that could predict these progressive developments to the eventual *ultimate* outcome.

o **External validity**

External validity refers to establishing the domain to which a study's findings can be generalised. With regard to the previous two issues Olivier (2004), is of the opinion that this represents the major concerns with any experimentation. Firstly, that the observations are indeed caused by experimental inputs alone and nothing else (*internal validity*), and secondly that the results of the experimentation can be generalised (*external validity).* Most of these problems associated with validity can be addressed during the design phase in the compilation of the research protocol. The protocol defines the research procedure and rationale thereof, and which could be scrutinised prior to experimentation. Validity in exploratory work according to Olivier (2004) is less of an issue due to the nature of the research, but it remains the product of careful deliberation.

2.2.3.5. Case study designs

Yin (2003) proposes four basic types of designs for case studies that are a combination of choices in terms of whether a single or a multiple cases study research approach will be followed; as well as the choice in terms of the unit of analysis that will be selected. In a situation where multiple units of analysis are selected, the research design is referred to as an embedded design. These choices will be briefly reviewed below:

- **Single or multiple designs:**

A number of considerations would influence one's choice in terms of a single or multiple case study design**.** The following rationale is presented for the use of single case study research:

- **Single case study designs**

The critical case

The critical case is used to test a well-formulated theory. The theory has a clear set of propositions which are believed to be true given a specified contextual environment. One may wish to use a single case study to confirm, challenge or to extend the theory.

An extreme or unique case

This occurs when a very rare phenomenon is investigated such as a specific injury or disorder where it is considered to be worthwhile to document and analyse the case.

The representative or typical case

The objective here is to record what is believed to be a typical representative case that could be used for informative purposes.

The revelatory case

The revelatory case is sited as a situation where an investigator has the unique opportunity to investigate a phenomenon that was previously inaccessible to scientific research.

Longitudinal case

The longitudinal case deals with the same case over an extended period of time where the objective is to observe how conditions change over time.

- **Multiple case study designs**

As far as Yin (2003) is concerned, there are no methodological differences between a multiple and single case studies, as found in anthropology, and political sciences. In this regard he cites Eckstein (1975), Lijphart (1975) and George (1979).

Multiple case studies however holds distinct advantages from the perspective that the evidence from such studies are often more compelling and the study thus regarded as more robust. The underlying logic for selecting a multiple case design is the same. According to Yin (2003) each case must be carefully selected in order to achieve one of the following objectives. It must either predict similar results (i.e. *literal replication* of results) or predicts contrasting results but for predictable reasons (*theoretical replication*). The importance of a rich theoretical framework to enable such replication is thus strongly emphasised by him. The framework should thus state under which conditions the particular phenomenon is likely to occur *(literal replication)* and under which conditions not *(theoretical replication).*

It is important to realise the methodological differences between "*replication logic*" in multiple case study designs and "sampling logic" as encountered in multiple subjects in an experiment. A major insight is to consider multiple cases as one would consider multiple experiments. Any application of sampling logic would be misplaced. The following reasons cited by Yin (2003) are briefly listed:

i. *Case studies are not the best method for assessing the prevalence of a phenomenon.*

ii. *If used for such purposes the case study will have to cover both phenomenon and contextual variables which would require very large sample sizes to enable any statistical consideration.*

iii. *If sampling logic had to be applied to all types of research, many important topics could not be empirically investigated.*

It is also important to note that each case study is a *"whole study"* in which converging evidence is sought regarding facts and conclusions. A last comment on this issue is that it is not uncommon to adapt or modify the design of subsequent cases in order to accommodate new insights. Without such *"redesigns"*, according to Yin (2003), one risks being accused of distorting the enquiry in order to accommodate the original design.

- **Holistic or imbedded designs:**

Holistic versus imbedded designs deals with the unit of analysis. Holistic designs deals with only one unit of analysis where the multiple case study design deals with multiple units of analysis, i.e. subunits within the unit.

- **Holistic designs**

Holistic case studies are shaped by a thorough qualitative approach that relies on narrative, phenomenological descriptions (Scholz & Tietje, 2002). Scholz & Tietje cite Stake (1995) who claims that themes and hypotheses may be important but should remain subordinate to the understanding of the case.

- **Imbedded designs**

Embedded case studies according to Scholz & Tietje (2002) involve more than one unit, or object, of analysis and are not limited to qualitative analysis. It allows for the analysis of a multiplicity of evidence in *"subunits, which focus on different salient aspects of the case"*.

The combinations of alternative designs that one can create based on the selection of the aforementioned alternatives, are reflected as a two-by-two matrix which is shown in Table 2.3. These alternatives are referred to as *Type 1*, *Type 2*, *Type 3*, and *Type 4* designs respectively.

Table 2.3: Basic types of designs for case studies

Type	Single-case design	Multiple-case design
Holistic	**Type 1** Single-case; single unit of analysis	**Type 3** Multi-case; single unit of analysis
Embedded	**Type 2** Single-case: multiple units of analysis	**Type 4** Multi-case: multiple units of analysis

- **The design as a process perspective**

Yin (1994) describes case study design as a process consisting of the following steps:

- **Step 1: Develop a hypothesised understanding of the case study**

Yin (1994) stresses the importance of having a thorough understanding of the intended operation and the expected outcomes with explicit attention to the contextual conditions. He also highlights the importance of being open to the potential need for modification later on. According to him the programme should at least reflect:

- The "*programme logic model*" tracing the causal flows of the programme, and
- An emerging taxonomy of contextual conditions within which the programme operates.

- **Step 2: Emerge this understanding within previous research**

By emerging this understanding within previous research one should be able to identify rival theories and hypothesis for the programme (*phenomenon under investigation)*. This holds the following potential benefits:

- The hypothesised understanding of the programme may be clarified further.
- Rival theories will lead to potent strategies for analysing data.
- The broader range of theory and practice will be the main vehicle for generalising the results of the evaluation.

- **Step 3: Tentatively define the unit(s) of analysis**

Define the main units and sub-units of analysis.

- **Step 4: Establish a schedule and procedure for interim reports**

Although Yin (2003) highlights the need for a formal schedule to review interim and final results of the study, it is not clear from the text to exactly what the benefits involved are. Two of the potential benefits could include:

  - Formal feedback on the progressive development of the research project provides for the opportunity to reflect on the progress made and allows for redirection of efforts in resolving the research questions involved.
  - Such a schedule will pace the execution of the research.

- **Step 5: Define and test instruments, protocols and field procedures**

The testing and validation of the aforementioned are crucial to the validity of results.

- **Step 6: Collect, analyse and synthesise data**

It is important to realise that the data collection and analysis are likely to occur in an intermingled way and not chronologically. It is essential to document the methodological steps thoroughly in order to ensure an unbiased data collection process despite variation in individual cases.

- **Step 7: Create a data base**

Organise both quantitative and qualitative data systematically to permit an efficient access process.

- **Step 8: Analyse the evidence**

The data analysis process could evolve a wide range of techniques and it is also important to realise that the analysis process might identify the need for additional data collecting – again with the necessary methodological caution.

- **Step 9: Compose the case study report**

Essential characteristics of the report are that it is separate from the database and that it contains explicit presentations of the key evidence used to draw conclusions.

Although not explicitly stated, it is assumed that the case study design must address all of the above.

2.2.3.6. Dimension and classification of case studies

Scholz & Tietje (2002) provide the following framework for the classification of case studies which is reflected in Table 2.4.

Table 2.4: Dimensions and classifications of case studies

Dimension	Classification
Design	Holistic or imbedded Single case or multiple case
Motivation	Intrinsic or instrumental
Epistemological status	Exploratory, descriptive, or explanatory
Purpose	Research, teaching or action/application
Data	Qualitative or/and quantitative
Format	Highly structured, short vignettes Unstructured or ground braking
Synthesis	Informal, emphatic, or intuitive Formative or method driven

Although most of the aspects reflected in Table 2.4 have been covered in the previous sections, it is worth while to review some of the dimensions listed.

Intrinsic and instrumental

Intrinsic motivation refers to research undertaken purely as a result of the interest of the researcher and is aimed solely at understanding the particular case. If the objective differs, it becomes instrumental. Case studies that are aimed at furthering scientific knowledge thus become instrumental.

Epistemological status

Epistemological status refers to the classification as either exploratory, teaching, or action/application which has been discussed in the introduction to case study research.

Format

The format of the case study would vary according to the nature of the research with a lesser degree of structure with exploratory and groundbreaking research.

Synthesis

The classification in terms of synthesis deals with the manner in which the case study deals with knowledge integration. Holistic case studies tend to be narrative by nature whilst the embedded case study normally deals with both quantitative and qualitative data, and associated strategies for integration (Scholz & Tietje, 2002). The aforementioned researchers make use of the so-called "Brunswikian lens model" for synthesis and knowledge integration. These powerful concepts are discussed in 2.2.4.

2.2.3.7. Protocol

According to Yin (2003) the protocol contains instruments as well as the procedures and general rules that must be used in the application of the protocol. He also states that protocol is directed at the investigator or researcher and not the entity that the research is dealing with. He also concludes that a protocol is advisable in all circumstances, but essential for multiple case studies.

Protocol structure

The structure of the protocol can be briefly summarised as follows:

- **Overview**

- Background
- Substantive issues being investigated
- Relevant readings about the issue

- **Procedure**

- The procedure to be followed
- The consent form

- **Case study questions**

- General orientation: - the questions are directed at the researcher as a reminder of what information is required, and not at the interviewee. Each question should be accompanied by a list of likely sources of evidence.

Note: It is important to note that the questions form the structure of the enquiry and are not intended as literal questions to be asked of the interviewee. It thus provides guidance to the researcher.

- Level of questions:

  i. Level 1: Questions asked of a specific interviewee.
  ii. Level 2: Questions to be answered by the investigator for every individual case.
  iii. Level 3: Questions asked of the pattern of findings across multiple cases.
  iv. Level 4: Questions asked of an entire study, e.g. calling on information beyond the case study evidence, including literature or other published data.
  v. Level 5: Normative questions about recommendations and conclusions beyond the narrow scope of the study.

- **Collecting data – sources of information**

- Documentation: - for case studies the use of documents are corroborative and augments evidence from other sources.

- Archival records: - Other formal records to support evidence.
- Interviews: - It is worthy to note the open-ended nature of questions.
- Direct observations, inclusive of participant observations by the researcher.

o **Reporting Case studies**

Yin (2003) proposes the following criteria for exemplary case studies.

o **Case studies must be significant**

Exemplary case studies anticipate obvious alternatives and even advocate their positions as forcefully as possible, and then show empirically on what basis these should be rejected.

o **Case studies must display sufficient evidence**

Critical pieces of evidence must be contained within the case study report. An exemplary case study represents judiciously and effectively presents the most relevant evidence, so that the reader can reach an independent judgement regarding the merits of the analysis. With multiple case studies the researcher should convince the reader that the individual case studies have been treated fairly and that cross-case conclusions have not been biased by undue attention to one or a few of the array of cases.

Finally evidence should be provided about the validity of the evidence. It does not imply that all the cases must be burdened with the full methodological treatises. A few judicious footnotes or words in the preface of the case study can cover the critical validation steps.

o **Case studies must be composed in an engaging manner:**

The report should be engaging. For written reports it implies a clear writing style, which entices the reader to continue reading.

In the next section the synthesis and integration of knowledge will be discussed. It will also include the so-called "Brunswikian lens model" as the basis for alternative models for synthesis and knowledge integration.

2.2.3.8. Synthesis and knowledge integration in imbedded case study research

This section deals with the architecture of knowledge integration in embedded case studies as well as an overview of methods that could be used in this regard.

- **Levels of knowledge**

Scholz & Tietje (2002) postulate that case studies should be organised and structured on three levels which are represented in Figure 2.1.

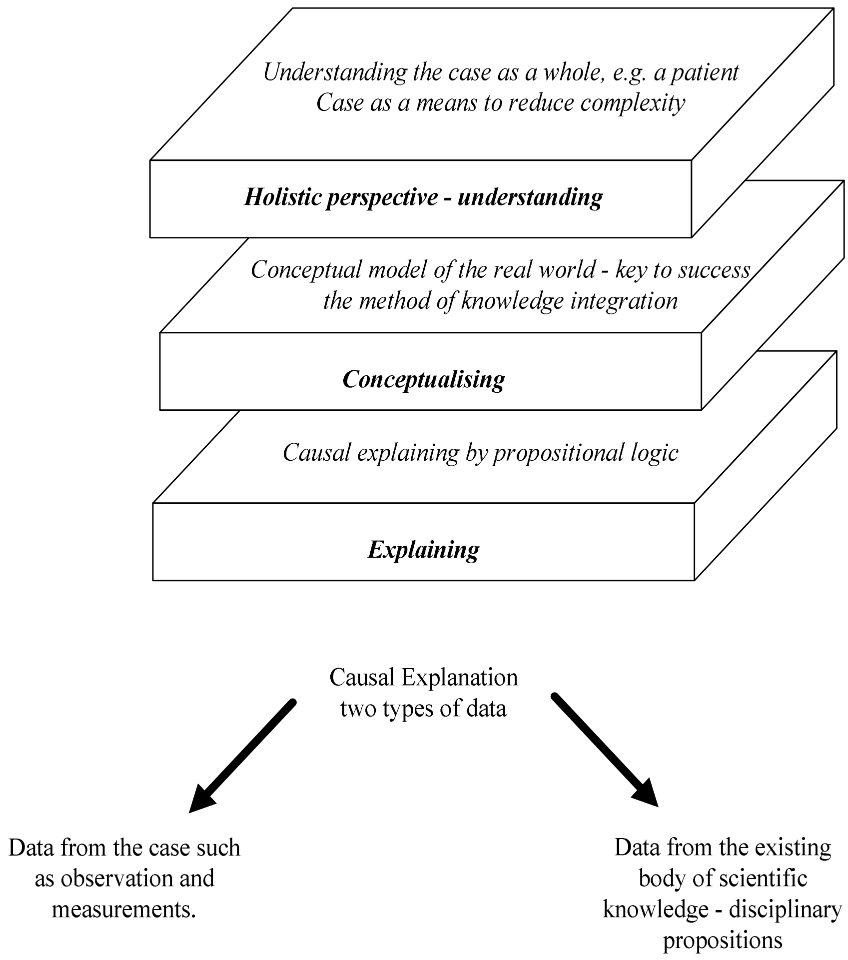

Figure 2.1: Theory of knowledge

On the first level the objective is to reduce the complexity associated with the discourse of general problems, to one individual state of affairs as encapsulated by the case.

On the second level the case is generalised through the creation of a conceptual model. According to Scholz & Tietje (2002) the key to success on this level lies in the methods used for knowledge integration. These methods aid in the creation of valid understanding and become the vehicles for knowledge integration. This researcher equates this second level with the theoretical model as advocated by Yin (2003).

On the third level are scattered data and results from subprojects. Two types of data exist. The first is the outputs from the case study research, such as data, observations, measurements, surveys, documents and expertise. The second is data from the existing body of scientific knowledge in the form of disciplinary propositions. With regard to the second data element, namely an existing theoretical model, one could argue that if it forms the basis of the replication logic as advocated by Yin (2003) and that it could be considered as level-two knowledge. This argument is based on the fact that Scholz & Tietje (2002) see level two as the vehicle for knowledge integration, and thus for the generalisation of findings.

o **Strategies for synthesis**

Scholz & Tietje (2002) see synthesis as the scientific combination of often-varied data, information and ideas into a consistent whole. Knowledge integration according to them can be seen as a kind of synthesis designed specifically for each case study type. A number of approaches to synthesis exist and a few will be briefly reviewed (Scholz & Tietje, 2002).

▪ **Synthesis based on an epistemological perspective**

The authors cite four types of synthesis based on an epistemological perspective, namely: synthesis as a philosophical strategy of contemplation, synthesis through a pure case model, synthesis as a pre-stage of higher conceptual knowledge and synthesis as a method for complex problem solving.

Synthesis as a philosophical strategy of contemplation

Synthesis as a philosophical strategy of contemplation reverts back to a pre-scientific, contemplative approach where case results are the basis for reflection in order to gain understanding and insight into the meaning, true nature and essence of the case study

Synthesis through a pure case model

The pure case model is based on the so-called Leibnizian model. Leibniz (1664-1716) proposed that one could descend from the general rules of truth to the composed. A critical element in this argument is that the rules of truth had to be found by analytical methods. The most general truths are the natural laws. The authors cite Churchman (1971) who noted that the Leibnizian model relied on the assumption that the truth was provided in the model.

The authors conclude that the Leibnizian model as a strategy for synthesis is appropriate at least as a partial synthesis, particularly for natural sciences.

Synthesis as a pre-stage of higher conceptual knowledge

Scholz and Tietje (2002) compare analytic and synthetic reasoning at the hand of the comparison between concept and perception as proposed by Immanuel Kant (1724-1804), in the sense that both are regarded as prerequisites for analytical reasoning and theoretical concepts. The following quote from Scholz and Tietje (2002:34) encapsulates the essence of this line of reasoning.

> *"The validation of hypothesis-based theory testing thus shows some reference to the Kantian concept and perception. The perceptual side represented by the theories and their hypotheses, and the analytical side is represented by the observed data. Empirical data substantiates, differentiates, and refutes the theories. Clearly, in the Kantian type of inquiry, the theory, not the case, is the point of reference".*

Synthesis as a method for complex problem solving

This strategy is based on the Hegelian model of inquiry (Schulz & Tietje, 2002). This approach follows an intermediate state of analysis that consists of different and even contradictory models of the case. According to this perspective the truth is approached in a dialectic way. The synthesis incorporates certain aspects from different world models which result in a new, larger model. This approach is particularly appropriate for ill-structured problems such as management, education, politics, urban planning and environmental sciences according to the authors.

- **Types of knowledge integration**

Schulz and Tietje (2002) distinguish between four types of knowledge integration. These are briefly listed as an additional element of contextualisation of the research.

- **Disciplines**

  This method of integration looks at the integration of knowledge from a disciplinary context, such as natural sciences and the arts.

- **Systems**

  The systems approach differentiates based on the subsystems that exist within the larger system boundaries. According to the authors the synthesis of subsystem can often be considered as a partial synthesis that are then subject to further knowledge integration and synthesis.

- **Interests**

  The use of interest as the basis for integration and synthesis could for example include the mediation of values between the various interest groups involved in the case.

- **Modes of thought**

  This aspect refers to the way in which the participants view the case from a cogitative or conceptual perspective, e.g. left-brain versus right-brain thinking. It refers to the way in which the case mentally or externally represented.

- **The Brunswikian Lens Model**

Schulz and Tietje (2002) have adapted the so called Brunswikian Lens Model as a generic framework that they use as an integrating framework for a variety of methods for knowledge integration. The model was initially developed by an experimental psychologist who worked in the field of perception (Brunswik & Tolman, 1935).

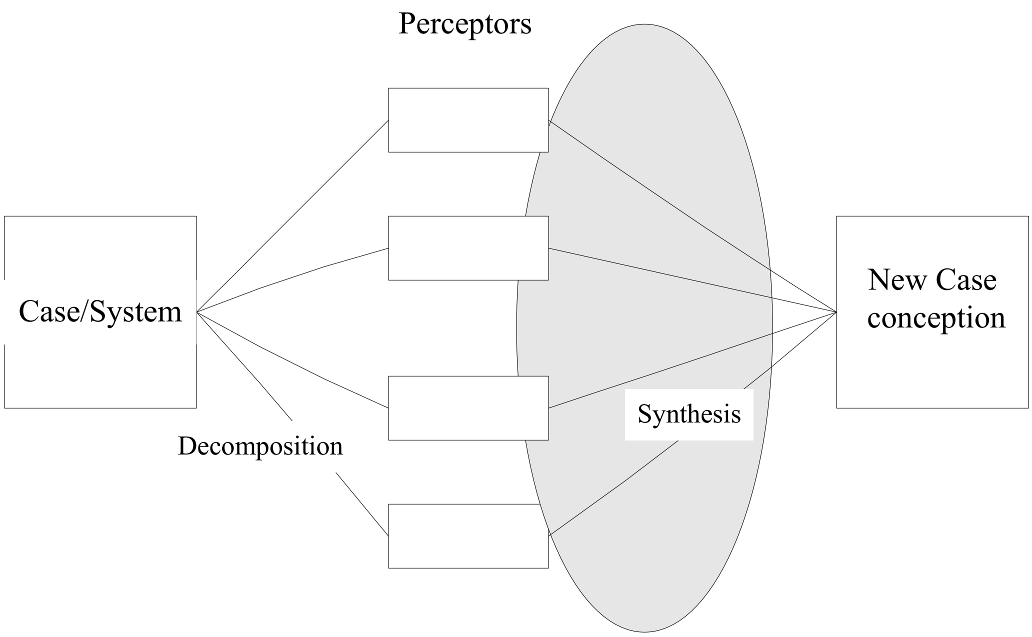

Figure 2.2: Brunswikian Lens Model

The model as developed by Brunswik and Tolman (1935) is fairly complex and technical and has no direct bearing on this research. The basic model however provides a useful conceptual framework for dealing with knowledge integration which is used in this research. In essence the process model deals with the decomposition of the case under consideration into subunits or functions. An assessment and analysis of these subunits are performed through a process of perception performed by so called *preceptors*. The integration of these different perceptions leads to a new conception of the case under consideration. The basic model is reflected in Figure 2.2.

Although a wide variety of models are referred to in the work of Schulz & Tietje (2002), only three that are considered to be relevant in terms of this research will be briefly listed in the following section.

- **Different types of knowledge integration**

  - **Formative Scenario Analysis**

Formative Scenario Analysis generates hypothetical future states of a system/case which are referred to as scenarios that assist in the process of gaining insight into the system and its dynamics. The scenarios are based on a sufficient set of system variables and are judged according to possibility and consistency.

  - **System Dynamics**

System Dynamics deals with a family of mathematical models that provide insight into the dynamic characteristics of the system. It thus not only provides insight into the eventual steady state of the system, but also address the transient behaviour, i.e. how the characteristics of the system, or variables, change with time.

  - **Multi-Attribute Utility Theory**

Multi-Attribute Utility Theory represents a group of methods that describes and models integral evaluations based on different attributes. The criteria may represent different interests, subsystems or disciplinary perspectives.

Although none of these models as presented in the work of Schulz & Tietje (2002), is applicable in the form as presented, the conceptual frameworks in conjunction with the Brunswikian Lens Model is considered useful for handling knowledge integration in the context of this research project. This is especially applicable projects of a mixed-methodological nature which followed with this research.

2.2.3.9. Case study protocol as design

In the previous sections a number of perspectives on the design of case studies have been presented. None of these perspectives provide a clear concise definition of exactly what such a design entails. A strong common ground exists between a number of authors such as Yin (2003), Olivier (2004) and Payne and Williams (2005) in that they see the protocol as a significant mechanism to define the scope and extent of the research. It also serves as a crucial role in defining the approach and ground rules and thus provides a reflection of the validity of the research.

In this research the *design* of the case study will be referred to as the *protocol* of the research. The objectives of the protocol remain the same as what is propagated by the aforementioned authors in terms of the design, i.e. to provide direction, methodology, structure, instruments, procedures, validation requirements, to name a few, as a guide to the researcher for getting from the beginning to the end of the research project.

In an attempt to ensure that the collective perspectives of the authors covered in the literature research, are embodied in the protocol, use has been made of a conformance matrix which is represented in Table 2.5. The objective with the matrix was to ensure that all the significant issues referred to in the literature research (i.e. those issues reflected on the left hand side of the table) were reflected in the subheadings that were created for the protocol, and that all these issues are incorporated in the case study design.

This section provides a brief overview and background to the particular section of the research. It also reflects the classification of the case study research approach.

The case study protocol used in this thesis consists of the following sections.

- **Overview**

A brief overview of the objectives and classification of the research is provided.

- **Study's questions**

The case study's questions provide the researcher with a general orientation to the answers that are required with reference to the likely sources of evidence. It will also classify the questions into the various levels as discussed earlier.

- **Theoretical framework**

This section will cover the underpinning of the research questions in the form of the theoretical model or hypothesis that has been developed in support of the research objective.

Table 2.5: Case study protocol conformance matrix

	Overview	Study's Questions	Theoretical framework	Propositions	Rival theories	Units of analysis	Schedule	Procedures	Data collection	Data analysis	Synthesis	Database	Knowledge integration	Consent	Quality assessment
Design classification	x														
Design components															
Study's questions		x													
Theoretical framework			x												
Propositions				x											
Unit of analysis						x									
Variables								x							
Data collection method									x						
Role of theory			x		x										
Quality assessment															x
Protocol															
Overview	x														
Procedure								x							
Consent														x	
Case study's questions		x													
Data collection									x						
Synthesis											x				
Process perspective															
Theoretical base (1)			x												
Rival theories (2)					x										
Units of analysis (3)						x									
Schedule & procedure (4)							x								
Define instruments, etc (5)								x							
Test instruments (5)								x							
Collect data (6)									x						
Analyse data (6)										x					
Synthesis (6)											x				
Create database (7)												x			
Knowledge integration (8)													x		

- **Propositions**

The propositions or expectations in terms of research outcomes based on the theoretical framework.

- **Rival theories**

This section covers the rival theories to the postulated theoretical framework. This includes the Null hypothesis, i.e. that the observations is a result of chance; and that a different theoretical model exists that will explain the observations, or deductions made.

- **Unit(s) of analysis**

The units of analysis are defined in relation to the level of research questions that are being posed.

- **Schedule and reviews**

The schedule reflects the planned feedback on progress made as well as the time frame for the research.

- **Instruments and procedures**

The section on instruments and procedures addresses two aspects, namely the definition as well as the validation of the instruments and procedures that are to be used in the research project.

- **Data collection**

This section defines the data collection methods to be used, as well as how the data collection process will be handled.

- **Data analysis**

The data analysis section will define how the data will be analysed.

- **Synthesis**

This section deals with the synthesis of data and observation by integrating it with the theoretical propositions to establish new concepts of causal relationships. Within this thesis a distinction is made between synthesis and knowledge integration. The last concept is reserved for the final integration of the results from embedded case studies.

- **Database**

This section deals with the structure and format of the database for the recording and retrieving of data.

- **Knowledge integration**

This section deals with the higher levels of knowledge integration of embedded case studies as covered in 2.3. It deals with the final conceptualisation of the case based on the triangulation of results and adapting the holistic understanding of the research case.

- **Informed consent**

This section contains the informed consents from the subjects involved in the case studies.

- **Quality assessment**

This section incorporates the aspects discussed in section 2.2.3.4 on the criteria for the quality of research designs. It deals with the measures for construct, internal, external validity and the reliability of the case study process. In this thesis the protocol will be defined for a group of similar case studies, with annotation of individual deviations as they occur.

2.2.4. Experimental study designs

According to Olivier (2004) the researcher is confronted with two major concerns. The first is that the observations are indeed caused by the experimental inputs and nothing else. The second is whether the results observed during the experiment can be generalised. The reader will be able to relate these concerns to that which was discussed earlier in the section on case study design. The first concern thus deals with *internal validity* and the second as *external validity*. The use of control groups is a common technique to ensure internal validity for experimental research or comparisons of techniques. The discussion that follows is based on extracts from the work by Olivier (2004).

- **Two-group experimental designs**

This design selects the subjects for the experimentation, and then splits the group randomly into two. The one group becomes the focus of the intended experimentation whilst the second group fulfils the role of a control group. A fundamental assumption of the technique is that since the groups were randomly composed, that they will be equal in all respects. The potential problem with two-group experiments is that the two groups are not the same. In such a situation one-group experiments are attractive.

- **Single groups**

Single group experiments are experiments where the subjects are subjected to observation of their behaviour with the *unmodified* system, and then subsequently subjected to the modified variables. The group thus become their *own control*.

- **Blind experiments (application by others)**

The aim of blind experiments is in essence to eliminate the psychological effects that the knowledge of the experimentation have on both the participants (subjects) and the researcher. Blind experimentation in general refers to the situation where the participant is not aware whether he is being subjected to the control treatment or the actual experimentation. Double blind refers to the situation where neither the subject nor the researcher is aware of what the treatment entails, i.e. the control treatment or the actual experimental treatment. In certain circumstances blind experimentation could also imply a situation where the application of experimental activities is performed by people other than the researcher.

The research was primarily based on multiple case study designs although blind experimentation was employed during some of the experimental research projects. The decision to use case studies as the primary research approach was based on the fact that the literature research revealed no information on conservative treatment approaches aimed specifically at the fascia. This forced the research to address the problem from an exploratory perspective for which a series of case studies as an exploratory device is considered as the most appropriate (Holloway, 1997).

The assessment, management and outcomes of the different subjects were described as separate case studies. Each case study was analysed individually and the knowledge gained was progressively integrated in the approaches followed with subsequent case studies. Thereafter the results of the separate case studies were compared (cross case) to one another (Yin, 1994; McDonnell *et al*., 2000).

2.2.5. Conclusion

Case study research as a research methodology has been reviewed in a fair amount of detail. This has been done due to the fact that qualitative research methodologies are not that common in the research field. It is also important that the concept of replication is thoroughly understood due to the vital role that the replication of results plays in the research project. Results are predicted based on the causal relationships of an underlying theoretical model that the researcher tries to prove by means of the replication of predicted results derived from the model.

2.3. POSTERIOR COMPARTMENT SYNDROME

2.3.1. Introduction

Exercise related injuries of the lower leg are often encountered in athletes (Mouhsine *et al*., 2006). Although it is generally accepted that the chronic compartment syndrome is as a result of exertion and/or overuse (Allen & Barnes, 1986; Balduini *et al*., 1993), experimental results suggest that other factors are responsible for the condition (Reinking, 2006). Reinking (2006) found little evidence to support the claims that extrinsic factors such as training volume, training surface, shoes and sport activities are the origin of the problem.

Chronic compartment syndrome is however also difficult to diagnose (Edwards *et al.*, 2005) and is as a result a problem not only to the athletes but also to the health care professionals. Even in situations where the condition is correctly diagnosed, the treatment interventions are not always successful (Edwards *et al.*, 2005; Mouhsine *et al.*, 2006). It is generally accepted that the condition is as a result of non-compliant fascia that encapsulates the compartment (Qvarfordt *et al.*, 1983; Detmer *et al.*, 1985). The use of fasciotomy as intervention is often selected but also often without the required successes (Mouhsine *et al.*, 2006). The athletes are understandably also not keen on a surgical intervention, while the conservative option has not produced any long term solutions to the problem. Cases are encountered where subjects were subjected to prolonged treatment and examination where the physicians fail to successfully diagnose and treat the subject (Mirabelli & Dimeff, 2006). In these cases the subject often forfeit their sport activities as a result of the pain induced during sport activity. The success rate of fasciotomy with the surgical decompression of the posterior compartment varies between 50% and 75% (Slimmon *et al*., 2002).

This portion of the literature review focuses on the investigation of CPCS. The objective is to provide a comprehensive overview of the current theoretical perspective of the condition, inclusive of the pathogenesis of CPCS. This also includes the identification of factors that might precipitate or perpetuate the symptoms as well as factors that could contribute to the development of a successful conservative treatment approach to the treatment of the symptoms of CPCS in runners.

2.3.2. Chronic Compartment Syndrome

2.3.2.1. Anatomy of compartments and their muscles

According to anatomical texts, the leg is divided into four separate osseofascial muscle compartments, namely the anterior compartment, the lateral compartment, the deep posterior compartment and the superficial posterior compartment. All of the compartments have both osseous and fascial borders, with the exception of the superior posterior compartment, which has only fascial borders. Each compartment contains specific muscle groups and associated tendons, blood vessels and nerves. The localization and diagnosis of the impaired compartment are based on a sound knowledge of the different anatomical structures in the lower leg (Ross, 1996). Davey *et al.* (1984) described a fifth compartment, namely that of the tibialis posterior muscle. According to them, the tibialis posterior muscle's compartment is contained in a separate osseofascial muscle compartment in which an isolated exertional compartment syndrome can occur. Detmer *et al.* (1985) take this view one step further by saying that their experience suggests that the arrangement of muscles within the four compartments is such that chronic compartment syndrome can develop within one subdivision of a compartment without involving other muscles within the same compartment. They conceptualize the leg as having seven functional compartments, namely the anterior-, the lateral-, the posterior superficial medial-, the posterior superficial lateral-, the posterior deep proximal-, the posterior deep distal (flexor digitorum longus, flexor hallucis longus and tibialis posterior) and the posterior superficial distal (distal soleus) compartment. The various compartments of the lower leg and the muscles they contain are reflected in Table 2.6.

2.3.2.2. Definition of chronic posterior compartment syndrome)

Chronic compartment syndrome is a pathological condition of skeletal muscle characterized by increased interstitial pressure within an anatomically confined muscle compartment which interferes with the circulation and function of the muscle and neurovascular components of the compartment (Nicholas & Herschman, 1995a). When this occurs in the posterior compartment of the lower leg, it is called a posterior compartment syndrome. From Table 2.6, it can be seen that the muscles that could be involved with a posterior compartment syndrome are the tibialis posterior-, the flexor digitorum longus-, the flexor hallucis longus-, the gastrocnemius-, the soleus- and the plantaris muscles. The neurovascular components that can possibly be involved are the posterior tibial- and the sural nerves. A condition is usually defined as chronic when it has been present for a period of longer than three months (Klenerman *et al.*, 1995; Von Korff & Saunders, 1996; Grabois, 2005).

Table 2.6: Summary of the anatomy of the compartments of the lower leg (Bouche, 1990)

Compartment	***Muscles***	***Vessels***	***Nerves***	***Weakness***	***Paraesthesia***	***Pain***	***Tenderness and tenseness***
Anterior	1.Tibialis anterior 2.Extensor hallucis longus 3.Extensor digitorum longus 4.Peroneus tertius	Anterior tibial artery and vein.	Deep peroneal nerve.	Ankle dorsi flexion and toe extension.	1st interspace between big and 2nd toes.	Ankle plantar flexion and toe flexion.	Anterior leg.
Lateral	1.Peroneus longus 2.Peroneus brevis	None.	Superficial peroneal nerve.	Ankle dorsi flexion and eversion.	Dorsum of foot.	Ankle plantar flexion and foot eversion.	Lateral leg.
Deep posterior	1.Tibialis posterior 2.Flexor digitorum longus 3.Flexor hallucis longus	Peroneal artery and vein Posterior tibial artery and vein.	Posterior tibial nerve.	Ankle plantar flexion; eversion and toe flexion.	Sole of foot.	Ankle dorsi flexion; foot eversion and toe flexion .	Medial leg.
Superficial posterior	1.Gastrocnemius 2.Soleus 3.Plantaris	None.	Sural nerve.	Ankle plantar flexion.	Dorsum and lateral foot.	Ankle dorsi flexion.	Calf.

Terms sometimes used as synonyms for chronic compartment syndrome (CCS) are *shin splints*, *medial tibial stress syndrome* and *chronic exertional compartment syndrome*. These terms will be described briefly.

The American Medical Association (AMA) has defined shin splint syndrome as *"pain and discomfort in the leg from repetitive activity on hard surfaces, or due to forceful, excessive use of foot flexors"* (AMA, 1966, pp 126). The AMA states that the diagnosis should be limited to musculo-skeletal inflammatory conditions; excluding stress fractures and ischemic disorders. Batt *et al*. (1998) agrees with the definition of the American Medical Association and feels that the term shin splints should be applied to any exertional lower leg pain not caused by stress fractures, compartment syndrome or muscle hernia. From this description it is clear that the phrase "shin splints" does not qualify as a synonym for compartment syndrome.

The term *medial tibial stress syndrome* seems to be closer in pathogenesis to compartment syndrome. Puranen (1974) believes the medial tibial stress syndrome is a deep posterior compartment syndrome caused by exercise-induced ischemia of the muscle in the medial fascial compartment of the leg. Mubarak *et al*. (1982) on the other hand have been unable to demonstrate an elevated pressure in the deep posterior compartment in patients diagnosed with medial tibial stress syndrome and have questioned the statement of Puranen (1974) that this condition is a compartment syndrome. A further opinion is that of Touliopolous and Herschman (1999) who state that medial stress syndrome is a result of injury involving the fascial origin of the soleus muscle or the periosteum beneath the origin of the tibialis posterior muscle.

In their view subjects diagnosed with a medial stress syndrome, experience pain over the middle and distal one third of the posterior-medial part of the tibia. The pain increases with activity and decreases with rest. According to Touliopolous & Herschman (1999), only two conditions can lead to the diagnosis of medial stress syndrome, namely a stress fracture or CPCS. If X-rays or a bone scan do not confirm a diagnosis of a stress fracture, the cause of medial tibial syndrome is CPCS. Detmer *et al*. (1985) has classified medial tibial stress syndrome into three categories, depending on the symptoms present. In the third category, which is a progression of the first two categories, Detmer *et al.* (1985) equates the medial tibial stress syndrome to a CPCS. This indicates the existence of a grey area between the CPCS and the medial stress syndrome in which it is not always possible to differentiate between the two conditions.

According to Wallensten (1983) there are two clinical conditions that can become chronic in spite of adequate non-surgical treatment, namely the medial tibial syndrome which he sometimes refers to as *shin splints* or *periostitis* and the *compartment syndrome.* Both these entities have, according to him, responded better to surgical than non-surgical treatment. As seen from the above discussion, it is very difficult to differentiate between a medial stress syndrome and a CPCS since the symptoms are similar and their response to both non-surgical and surgical management is very similar as well.

The term *chronic exertional compartment syndrome (CECS)* on the other hand may be a true synonym for CCS. Most authors agree on a definition for CCS that indicates a clinical condition that arises when increased pressure within a closed anatomical space compromises the function and blood flow within the area. The pressure usually rise transiently following repetitive motion or exercise, thereby producing temporary, reversible ischemia, pain, weakness and occasionally neurological deficits (Bouche, 1990; Hutchinson & Ireland, 1994; Howard *et al*., 2000). The term *exertional compartment syndrome* indicates that exertion is the cause of the raised interstitial pressure in the compartment.

The definition of CPCS which will be accepted for the discussion of the literature review and the application of the research methodology of this study is the following: "Chronic Posterior Compartment Syndrome is a pathological condition of skeletal muscle that has been present for a period of longer than three to six months. It is characterized by an increased interstitial pressure within the posterior muscle compartment of the lower leg which interferes with the circulation and function of the muscle and neurovascular components of the posterior compartment".

2.3.2.3. Pathogenesis of chronic posterior compartment syndrome.

There has been much speculation as to the pathogenesis of the chronic compartment syndrome. It is thought that with repeated contraction, an exercising muscle can increase its volume by 20% (Bourne & Rorabeck, 1989; Eisele & Sammarco, 1993). If this event occurs in a compartment surrounded by a non-compliant fascia envelope (Clanton & Solcher, 1994; Nicholas & Herschman, 1995b), compartment pressures are expected to increase. This increase in pressure then impedes blood flow and produces ischemic pain (Nicholas & Herschman, 1995b). The elevated compartment pressure increases pressure both on, and within intra-compartmental veins. The elevated venous pressure decreases the arterio-venous gradient, which reduces blood flow within the compartment. A disturbance of micro vascular flow leads to ischemia, depletion of high-energy phosphate stores, and finally cellular acidosis. The stage of ischemia is not necessarily reached in patients with chronic compartment syndrome. The symptoms of CCS, which will be discussed later, seem to appear with the rise in intra-compartmental pressure and decrease in blood flow even before ischemia sets in (Hutchinson & Ireland, 1994). These authors also describe the anatomic components contributing to compartment syndrome which may include a limited compartment size, increased intra-compartmental volume (increased capillary permeability or capillary pressure), and constricted fascia (loss of the elasticity of the compartment's fascia) or increased muscle bulk (hypertrophy). Mouhsine *et al.* (2006) also agreed with this pathogenesis.

Litwiller *et al*. (2007) wrote an article on a new proposed method of diagnosing chronic exertional compartment syndrome (CECS) in which they have stated that many theories existed to explain the etiology of CECS, but none has definitely been proven. They state, that in the case of CECS, there is a delay or barrier to the egress of fluid within the muscle compartment, possibly due to alterations in the basement membranes of vessels or in the fascia surrounding the muscles.

In summary, CCS or CECS is a condition in which the circulation and function of tissues within a closed anatomical space are compromised by increased pressure within the space. The symptoms that are produced because of the above-mentioned pathogenesis abate with periods of rest and return when exercise is resumed. In the case of CPCS, the circulation and function of the muscles and the neurovascular components are compromised in the closed anatomical space of the posterior compartment of the lower leg. According to Reneman (1975), bilateral leg involvement is common and occurs in 95% of patients. The following flow diagram illustrates the proposed pathogenesis of CPCS:

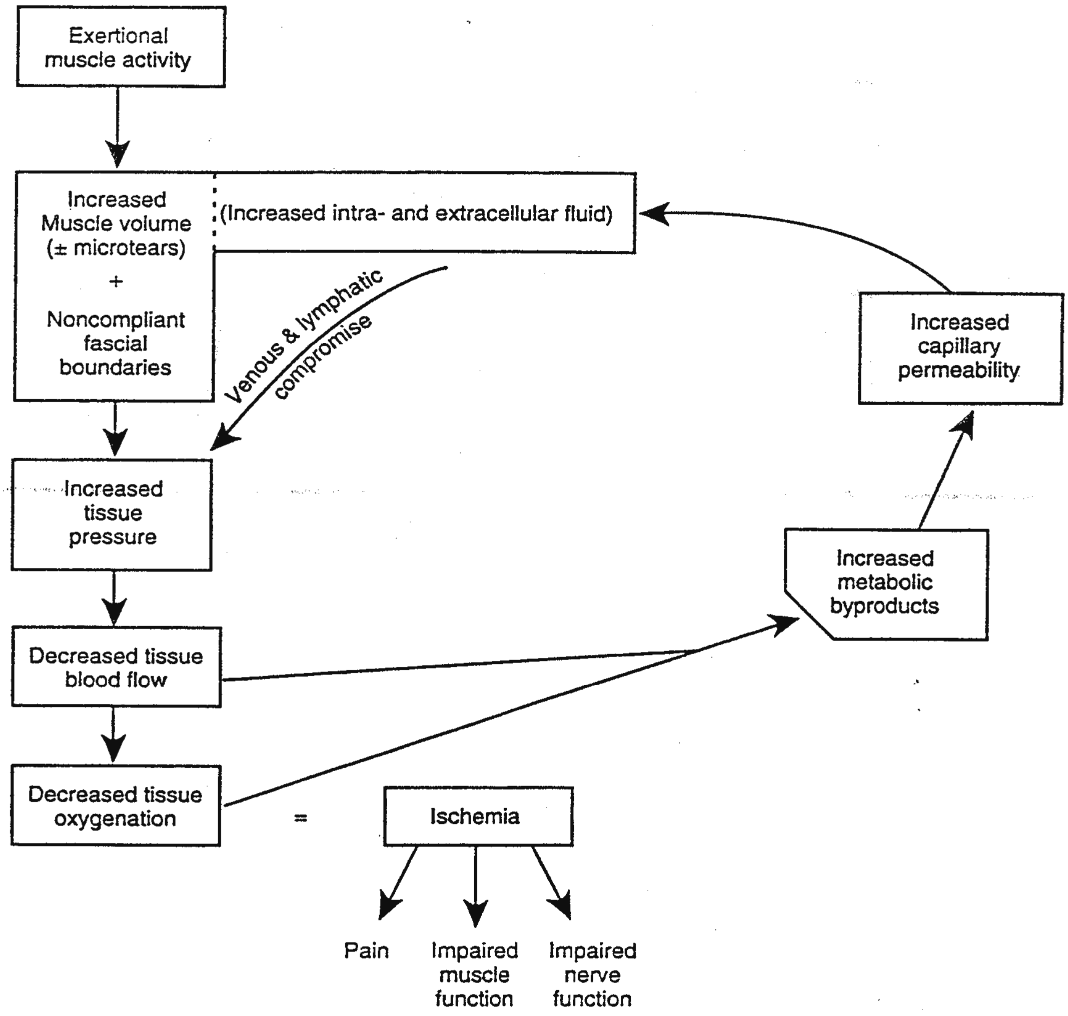

Figure 2.3: **Proposed pathogenesis of CPCS (Clanton & Solcher, 1994)**

2.3.2.4. Prevalence of compartment syndrome

Allen & Barnes (1986) as well as Mouhsine *et al.* (2006) concluded from research that CPCS is clinically seen less often than chronic anterior compartment syndrome (CACS). Allen & Barnes's sample group included 110 subjects (133 abnormal legs) presenting with exercise related pain in the lower leg.

No statistics were found in the literature with regard to the prevalence of CCS and specifically CPCS. The only statistics available were applicable to the incidence of stress fractures. Stress fractures have been reported to occur in 1.9% of college athletes (Goldberg & Pecora, 1994) and 31% of military recruits (Milgrom *et al.*, 1985).

Exercise-induced pain in the lower leg is said to be most common amongst runners, followed by ballet dancers. Detmer *et al.* (1985) have found that seven out of eight people presenting with chronic compartment syndrome were athletes, and predominantly runners. According to Davey *et al.* (1984); Detmer *et al.* (1985) and Brukner (2000) chronic compartment syndrome is more common in the anterior (70%) and the deep posterior compartments (10%) than in the lateral or superficial posterior compartment. The occurrence of chronic compartment syndrome, in general, does not seem prevalent at all. See Table 2.7 for a summary.

Table 2.7: **Summary of the occurrence of chronic compartment syndrome**

Author	*Subjects referred*	*Subjects diagnosed*
Martens, *et al.*, 1984		29
Pedowitz *et al.*, 1990.	150	45
Rettig *et al.*, 1991		21*
Clanton & Solcher, 1994	150	33
Styf, 1998	98	26**
Blackman *et al.*, 1998		7

* Over a period of three years

** Over a period of five years

2.3.2.5. Symptoms of chronic posterior compartment syndrome

Clinically patients with symptoms of chronic posterior compartment syndrome complain of activity-related pain and a feeling of tightness that begins within a predicted period of time after the commencement of the exercise or after reaching a certain level of activity. Typically, the patient will report pain over the posterior compartment. The pain usually begins as a dull or cramp-like ache and increases in intensity if training persists. The pain will usually continue after the exercise has stopped, but is fully relieved by rest, usually about 20 minutes after completion of exercise. Stretching of the involved muscles (gastrocnemius-, soleus-, tibialis posterior- and flexor digitorum longus muscles) may also elicit pain. Patients occasionally report paraesthesia / anaesthesia in the foot (sole or dorsum and lateral aspect of the foot, depending on whether the superficial or deep compartment is involved (see Table 2.6)).

The pain can progress into weakness and instability of the ankle if recurrent ankle sprains occur due to the experienced paraesthesia or anaesthesia. Tenderness and tenseness can be palpated over the muscles (gastrocnemius- or soleus muscles) of the involved compartment (Martens *et al.*, 1984; Edwards & Myerson, 1996; Ross, 1996; Hutchinson *et al*., 1998; Touliopolous & Herschman, 1999; Garcia-Mata *et al.*, 2001; Litwiller *et al.*, 2007).

Exercise related pain in the lower leg can be caused by a variety of conditions. This makes differentiation essential in order to determine whether the patient's symptoms are caused by CPCS or whether the symptoms may be caused by another condition.

2.3.2.6. The differentiation of CPCS from other symptom related conditions

Conditions that can mimic symptoms of chronic compartment syndromes (also described as chronic exertional compartment syndrome or medial tibial stress syndrome) in the lower leg, are stress fractures, tendonitis (for example that of flexor hallucis longus), gastrocnemius strain, periostitis, spinal stenosis, radiculopathy, entrapments of arteries (most commonly the popliteal artery) and nerves, claudication (arterio-sclerosis), and effort induced venous thrombosis (Hutchinson *et al.*, 1998; Mirabelli & Dimeff, 2006; Reinking, 2006).

According to Brukner (2000) and Mirabelli & Dimeff (2006), shin pain can occur in one or more of three anatomical structures, namely: bone, periosteum and muscle compartment. To clarify the previous statement, examples are given: when repetitive strain is applied to the bone, a common reaction to this is the development of a stress fracture. When the periosteum is submitted to stress, inflammation develops at the insertion of muscles. This is especially applicable to the tibialis posterior- and the soleus muscle as well as the fascia attaching to the medial border of the tibia. All the muscle compartments are enveloped by fascia. The deep compartment contains the tibialis posterior-, the flexor hallucis longus- and the flexor digitorum longus muscle which can all refer pain to the posterior-medial part of the leg.

With stress fractures the patient will complain of pain at rest or an ache experienced at night. A stress fracture can be seen on X-rays although radiographic findings are normally negative during the first two to four weeks following the stress fracture. If the

X-rays are still negative after four weeks, a bone scan can be done. The technetium pyrophosphate bone scan is usually positive within the first week after presentation of symptoms if a stress fracture is present. With a stress fracture, it reveals a very focal uptake of technetium in the medial tibia. Clinically, hopping on the affected leg and percussion of the bone can be used as part of the objective assessment and these tests will elicit pain if a stress fracture is present. Ultrasound therapy seems to aggravate the symptoms if a stress fracture is present and can therefore be used as a diagnostic tool (Clanton & Solcher, 1994).

When the pain originates from a tendon or the periosteum in the lower leg, the pain tends to improve after warming up, in contrast to pain caused by a compartment syndrome which gradually worsens with exercise. In contrast to a stress fracture, a technetium pyrophosphate bone scan will show a diffuse linear uptake of the technetium along the posterior-medial tibia with a periostitis. Another interesting difference between pain caused by CPCS and periosteum involvement according to Blackman *et al.* (1998) is that the pain of CPCS is unrelated to ground contact.

Painful isometric muscle contractions of the various muscles of the posterior compartment are normally an indication of a partial muscle tear (Travell & Simons, 1999).

When pain in the lower leg is referred from a lumbar nerve root (radiculopathy), neurological conduction deficits will be identified with a neurological examination. There will be an area of decreased sensation (in a specific dermatome, indicative of a specific nerve root), decreased motor strength, decreased tendon reflexes or a combination of any of these factors (Maitland, 2006). Pain due to mechanical sensitivity of the lumbar-sacral nerve roots should however be differentiated with neural provocation tests (Butler, 1996).

Bilateral leg involvement of CPCS occurs in 95% of subjects with CCS (Reneman, 1975). Lumbar stenosis can however also be the cause of bilateral leg pain. The most characteristic features of spinal stenosis will be described in order to assist clinicians to differentiate between symptoms caused by CPCS and symptoms caused by spinal stenosis. The most common finding in a subject with lumbar stenosis is a decrease in lumbar spinal extension. Lumbar extension will normally reproduce or exacerbate the symptoms. Subjects will be more comfortable walking uphill than downhill and can walk further if they are bent forward while walking. They sometimes walk with a wide base, but a neurological examination often proves to be negative (in some cases, the various forms of sensation or light touch might be decreased) (Nowakowski *et al.*, 1996).

The following tests may assist the clinician to differentiate between vascular impairment, neurogenic impairment and symptoms of CPCS.

- The “bicycle test”: the subject cycles on a stationary bicycle with his spine first extended then flexed. In the case of vascular claudication, the change in lumbar posture will have no influence on his symptoms. In the case of neurogenic claudication, the subject will be able to cycle for a longer period of time with the spine in a flexed position before he experiences any symptoms (Nowakowski *et al.*, 1996).
- The “stoop test”: the test is positive for neurogenic claudication when flexion of the lumbar spine while walking or stooping relieves the limb symptoms. (Nowakowski *et al.*, 1996).

Other conditions that can mimic the symptoms of CPCS are neural entrapment syndromes. The most common neural entrapment syndrome, causing pain in the lower leg and often paraesthesia over the dorsal aspect of the foot, is that of the superficial peroneal nerve (Clanton & Solcher, 1994). The superficial peroneal nerve runs through the lateral compartment (Travell & Simons, 1999). In order to differentiate it from the posterior compartment syndrome, Tinel’s sign may be elicited by gentle percussions over the path of the superficial peroneal nerve (8 – 15 cm proximal to the ankle). Symptoms may also be elicited by pressing on the nerve where it emerges from the deep fascia (approximately one-quarter of the distance up the lower leg from the lateral malleolus) while doing dorsi flexion and eversion against resistance (Clanton & Solcher, 1994). Pain is normally experienced over the lateral side of the lower quarter of the shin. Swelling and diminished sensation might be present over the before mentioned area without any motor deficits (Kernohan *et al.*, 1985; Travell & Simons, 1999).

Although some of the symptoms (pain, swelling and sensational deficits) are similar to that of CPCS, the area of the symptoms differs.

Other possible nerve entrapments whose symptoms might mimic some of the symptoms experienced with CPCS are:

- entrapment of the posterior tibial nerve (which runs through the deep posterior compartment) with a high tarsal tunnel. Entrapment of the tibial nerve by the tendinous arch of the soleus muscle has been noted a couple of times before. This gives rise to pain in the popliteal fossa which is exacerbated with active or passive dorsi-flexion and by weight bearing. Entrapment of the posterior tibial nerve can cause pain behind the knee and a tingling sensation in the sole of the foot (Mastaglia, 2000; Mastaglia *et al.*, 2000)
- entrapment of the common peroneal nerve at the neck of the fibula (at the origin of the peroneus longus muscle). Entrapment of the common peroneal nerve weakens both the anterior and lateral compartment muscles. Loss of sensation in most marked in a triangular patch on the dorsum of the foot distally between the first and the second toes (Travell & Simons, 1999).
- entrapment of the sural nerve (which runs through the superficial posterior compartment) in the posterior part of the calf. Patients typically have a sub-acute onset of a neuritis type of pain such as burning, tingling or radiation (Clanton & Solcher, 1994). This pain is unlike the pain, stiffness or paraesthesia experienced with the chronic posterior compartment syndrome.

A vascular condition that can mimic symptoms of CPCS is entrapment of the popliteal artery. Popliteal artery entrapment syndrome is a relatively rare entity that causes calf pain in young athletes but it should not be disregarded as a possible diagnosis in a young athlete presenting with unilateral symptoms of intermittent claudication. Early symptoms may be vague and atypical for claudication. The symptoms can include cramping pain in the calf, paraesthesia and discoloration in the foot or toes, as well as temperature changes in the foot (Clanton & Solcher, 1994).

When claudication is present, the most common cause is compression of the artery beneath the gastrocnemius muscle. The pain increases with elevation of the leg as well as with exercise. The pain decreases with the cessation of exercise. The dorsalis pedis and posterior tibialis pulses should be palpated in order to help with the diagnosis of popliteal artery entrapment. In the case of popliteal artery entrapment, the pulses will be decreased or absent in contrast to the normal pulses in subjects with CCS. The increased intra-compartmental pressure in CCS is able to disturb only the capillary circulation - will not have any effect on the pulses. This capillary compression results in a relative ischemia, while the larger arteries are not involved and have normal pulses. A Doppler ultrasound or angiogram performed directly after the exercise can confirm the diagnosis of popliteal artery entrapment (Touliopolous & Herschman, 1999). Another difference between the symptoms of CPCS and popliteal artery entrapment is that the complaints of intermittent claudication in the popliteal artery entrapment syndrome disappear a few minutes after cessation of the activity. In subjects with CCS, the discomfort will persist until the intra-compartmental pressure is restored to a normal level (Lysens *et al.*, 1983).

Exercise-induced venous thrombosis is another vascular impairment that needs to be excluded as a possible cause of pain in the lower leg. With exercise-induced venous thrombosis, symptoms of swelling of the calf area and point tenderness over the calf will occur unilaterally, in contrast to the symptoms of CPCS which are often present in both legs. Homan's sign will be positive. Elevation of the leg will decrease the pain, in contrast to the symptoms experienced by popliteal artery entrapment. An ultrasonagraphic or venographic investigation is necessary to confirm the diagnosis of a deep venous thrombosis (Clanton & Solcher, 1994).

In summary, the following conditions that might mimic some of the symptoms of CPCS should be ruled out through a process of differentiation as discussed above:

- Stress fractures
- Tendonitis
- Periostitis
- Radiculopathy
- Spinal stenosis
- Vascular impairments (vascular claudication; exercised-induced venous thrombosis) and popliteal artery entrapment syndrome
- Neurogenic impairments (neurogenic claudication)

2.3.2.7. Intra-compartmental pressure measurement and the diagnosis of CPCS

Measurement of intra-compartmental pressure may provide an objective tool to confirm the diagnosis of CPCS.

Pedowitz *et al.* (1990) published a paper in which they suggested criteria for the measurement of intra-compartmental pressures in chronic compartment syndrome of the leg by means of the slit-catheter technique. The criteria suggested that a pre-exercise pressure of 15 mm Hg or more and or a one minute post-exercise pressure of 30 mmHg or more and or a five minute post-exercise pressure of 20 mmHg or more would be indicative of chronic compartment syndrome.

Allen & Barnes (1986) propose that pre-exercise resting pressures do not conclusively demonstrate compartment syndrome, and significant differences between normal and abnormal compartment pressures have been found only by means of statistical analysis.

In the measurement of the intra-compartmental pressures, the most emphasis has been placed on the time that it takes for the post-exercise values to return to the pre-exercise level. Reneman (1975), Mubarak *et al.* (1982), Rorabeck *et al.* (1983) and Wallensten (1983) all used this index, and although all concur that pressure in pathological compartments takes longer to return to its pre-exercise level, there is no agreement about precise criteria of pressure and time. Although it is generally agreed that higher pressures are found during exercise in cases of compartment syndrome, only Puranen & Alavaikke (1981) consider this raised pressure to be the most important diagnostic factor.

Several invasive methods are available to obtain intra-compartmental pressures. These include the continuous infusion technique, a wick catheter, a split catheter and the solid state transducer intra-compartmental catheter. Numerous potential sources of error are present with each method (Clanton & Solcher, 1994). According to Detmer *et al.* (1985), proper experience in measurement techniques is needed to assure accurate results and these results still need to be interpreted in the context of the clinical signs and symptoms.

A variety of side-effects and technical problems experienced with the measurement of intra-compartmental pressures have been described in the literature (Schepsis & Lynch, 1998). These side-effects include discomfort to the patient; injury to important deep structures in the proximal deep compartment which can result from a blind needle stab; obstruction of the catheter can occur and it could be argued that even a very slow infusion of saline could be dangerous to the patient. Furthermore, the accuracy of the measurements can be influenced by the exact location of the tip of the needle, the depth of the needle, the position of ankle and foot during pressure measurements and the force of contraction.

In a survey done by Williams *et al.* (1998) on the use of compartment monitoring devices in the diagnosis of compartment syndrome, the results demonstrated that the majority of the trauma- and orthopaedic surgeons surveyed in the United Kingdom, advocate making the diagnosis through a combination of clinical reasoning and compartment pressure measurements. However, less than half of the trauma centres surveyed had pressure monitoring equipment available and there was a marked variation in opinion regarding the threshold level for surgery when pressure monitoring was applied.

Chronic compartment syndrome is currently diagnosed using invasive intra-compartmental pressure measurements (Mubarak, 1981; Puranen & Alavaikke, 1981). Two new techniques that are non-invasive and currently being studied as substitutes for testing intra-compartmental pressures are: the Thallium Stress Test and Near Infrared Spectroscopy. Near Infrared Spectroscopy is an indirect tool developed for the monitoring of tissue oxygenation in exercising skeletal muscle in order to detect the de-oxygenation caused by high intra-compartmental pressures. It is a non-invasive, painless method, but one of its limitations is the fact that light absorption is altered with passage through tissue (Giannotti *et al.*, 2000).

MRI has been used in a limited way in attempts to diagnose CECS. The problem with a MRI test as a diagnostic tool in the condition of CECS, is the fact that 5 min have already elapsed since the running test have been done, and the pressures have already dropped by the time the scanner is ready to operate (Litwiller *et al.*, 2007).

Litwiller *et al.* (2007) feels that the currently accepted method of measuring intra-compartmental pressure is too invasive and potentially quite painful and because of this the test should only be performed when the suspicion for compartment syndrome is very high. They have development an improved MRI screening protocol for CECS using an in-scanner exercise protocol and novel dual birdcage coil design for improved scanning. Although the concept of the screening protocol is excellent, it still requires refinement for commercial exploitation.

Measurement of the intra-compartmental pressures might be valuable to differentiate between CPCS and medial tibial stress syndrome. However, in the light of the risks associated with possible complications and side effects revealed by the literature research, the question arises as to whether invasive intra-compartmental pressure measurement is worth the risks. It can therefore be argued that no gold standard exists for the measurement of intra-compartmental pressures.

2.3.2.8. Surgical management of chronic compartment syndrome

Allen & Barnes (1986) as well as Edwards & Myerson (1996) proposed that in order to make a definitive diagnosis, patients with symptoms of CCS should first be treated conservatively. If there is no improvement and symptoms persist for a period of three to six months or longer, surgery is recommended in the presence of an increased post-exercise intra-compartmental pressure.

Since compartment syndrome of the posterior compartment occurs less frequently than compartment syndrome of the anterior and lateral compartments (Rorabeck *et al.*, 1988; Mouhsine *et al.*, 2006), the outcomes of surgical interventions in compartment syndromes in general will be discussed.

Surgery entails the surgical decompression of the various involved compartments. This is called a fasciotomy (Micheli *et al.*, 1999). Occasionally a part of the fascia is also removed surgically. This procedure is called a fasciectomy (Slimmon *et al.*, 2002). According to Swain & Ross (1999), the deep posterior compartment does not respond as quickly or as well, to fasciotomy as the anterior compartment. Edwards & Myerson (1996) have established that in most studies the results of surgical releases of the fascia of the anterior and lateral compartments are more successful in terms of the alleviation of symptoms than are those of posterior fascia releases. Schepsis & Lynch (1998) as well as Mouhsine *et al.* (2006) agree that subjects with symptoms of CPCS do not seem to respond as well to surgery as subjects with symptoms of other chronic compartment syndromes. Only 13 out of their 20 patients with symptoms of CPCS responded satisfactory to the surgery. Rorabeck *et al.* (1988) subjected 25 patients with elevated compartment pressures to surgical fasciotomy of the respective compartments (anterior, 13; anterior and posterior, four; deep posterior, eight). There were three failures, all of whom had decompression of the deep posterior compartment. They have then suggested that fasciotomy of the deep posterior compartment should also include a formal release of the tibialis posterior muscle at the same time.

Wallensten (1983) studied the results of fasciotomy of the affected muscle compartment in eight patients with chronic anterior compartment syndrome and in nine patients with medial tibial syndrome (which he also calls a deep posterior compartment syndrome). Clinically, there was a complete relief of pain in all of the patients with chronic anterior compartment syndrome and in five of the nine patients with medial tibial syndrome. It was not mentioned how the pain was measured or how long post-operatively the follow-up assessment was done.

Howard *et al.* (2000) conducted a study in which they evaluated the outcomes in patients following surgical treatment (fasciotomy) of chronic exertional compartment syndrome (CCS) in the leg. Over a period of six years a questionnaire was sent to 62 patients who had received surgery for the symptoms of CCS. A clinically significant improvement was reported by 81% of the anterior/lateral compartment patients compared to 50% of the patients with deep posterior compartment involvement. The mean percentage of pain relief was 68%. Lower activity levels were reported by 22% of the subjects; six percent failed initial surgical procedures and required revision surgery. Five percent had subsequent operations for exercise-induced pain in a different compartment than the compartment that initially underwent surgery. The researchers concluded that despite the possibility that some patients have less favourable outcomes, experience complications, or need subsequent operations, fasciotomy is recommended for patients with CECS as there is no other treatment for this condition. According to the authors, possible reasons for better post-surgical results in the anterior and lateral compartment than in the posterior compartment may have been the presence of sub compartments, such as the tibialis posterior compartment within the deep posterior compartment; or entrapment of the popliteal artery.

Slimmon *et al.* (2002) combined a partial fasciectomy with fasciotomy for compartment syndrome in order to relieve pain and to prevent recurrences thereof. A self-administered questionnaire was given to 62 patients at a mean follow-up 51 months after the surgery. Of the 50 patients who underwent a single operation, 60% reported an excellent or good outcome. Average pain and pain-on-running were significantly reduced, although some subjects still reported considerable levels of pain. Fifty eight percent of patients were exercising at a lower level than before the operation and, of these, 36% of the patients cited the return of their compartment syndrome or the development of a different lower leg compartment syndrome as the reason for the reduction in exercise levels. Some subjects indicated early improvement followed by subsequent deterioration. Slimmon *et al.* (2002) concluded that this surgical technique reduces pain and allows the majority of patients to return to sports; however, patients should be counselled that they may not be able to return to their pre-injury level of exercise or remain pain free.

Shah *et al*. (2004) are of the opinion that conservative management of CCS has been highly unsuccessful in terms of alleviating or decreasing the symptoms of CCS. They propose that a considerable degree of success (a decrease or alleviation of some of the symptoms), can be expected after a fasciotomy of the involved compartments followed by a rigorous rehabilitation programme, though recurrence of symptoms is a reported complication.

One of the more positive surgical studies was reported by Turnipseed (2002). An open fasciectomy was performed in all patients with CCS and where applicable, the popliteal artery was released. Three hundred and sixteen anterio-lateral, 70 deep-posterior and 50 superficial-posterior compartments were treated. The mean follow-up period was 60 months. Of the 276 patients, 92% had full relief of symptoms, eight percent obtained symptomatic relief, but activity was limited because of new compartment symptoms.

According to Howard *et al.* (2000) 13% of patients have experienced post-operative complications. Some of the complications experienced by Detmer *et al.* (1985) during a fasciotomy were:

- artery injury, requiring repair
- haematoma
- superficial wound infection
- peripheral cutaneous nerve damage
- lymphocele and
- deep venous thrombosis.

According to Mouhsine *et al.* (2006) the reported complication rate of fascia release, is between 4,5% and 13% including nerve injury, infections, post-operative haematoma, recurrence of symptoms secondary to incomplete release, cosmetically unacceptable scarring, anaesthetic problems, muscle fascia adhesions, swelling, lymphocele or haemorrhage.

The literature summarized in Tables 2.8 demonstrates that the surgical release of the fascia is successful in a limited number of cases and that there are often surgical complications. A variety of possible complications exists and the results are not always satisfactory in especially the deep posterior compartment. Some of the muscle strength is sacrificed, at least temporarily if not permanently, when the fascial barrier is not present for the muscle to work against (Micheli *et al.*, 1999). It also takes 6 - 12 weeks before the runner is back on his former running programme. This implies that he is back at the stage of base training.

In order to make a definitive diagnosis, the patients with symptoms of CCS should first be treated conservatively for a period of three to six months before they are referred for possible surgical management (Allen & Barnes, 1986; Edwards & Myerson, 1996). It was however found from the literature review that study data for conservative treatments are sparse and largely unsuccessful. Fasciotomy, according to the literature review, is the only effective treatment for chronic compartment syndrome (Fraipont & Adamson, 2003; Bong *et al.*, 2005; Englund, 2005; Godon & Crielaard, 2005; Mouhsine *et al.*, 2006).

Table 2.8 (a): Outcomes of surgical interventions during 1983 to 1998

Researchers	***Number of subjects***	***Intervention***	***Outcome measure***	***Results***	***Complications***
Wallensten, 1983	Eight subjects with CSCS and nine subjects with chronic medial tibial syndrome.	Fasciotomy.	Clinical assessment and questionnaires.	CACS: no pain. Complete relief of symptoms in five out of the nine subjects with chronic medial tibial syndrome.	Not mentioned.
Allen & Barnes, 1986	110 subjects.	Subcutaneous fasciotomy of the affected compartment.	Reassessment of symptoms. Not mentioned how.	At least one type of CCS was diagnosed in 105 limbs. 12 were treated conservatively, 20 limbs were treated surgically. Of the balance of 73 limbs during follow-up three months later, all but three patients had improved.	Not mentioned.
Rorabeck *et al*.., 1988	12 subjects with bilateral compartment syndrome. Group 1: seven subjects with anterior or lateral compartment symptoms. Group 2: three subjects with symptoms of deep posterior compartment. Group 3: two subjects with symptoms of both the anterior and the deep posterior compartments.	Bilateral fasciotomy.	Follow-up symptoms were assessed six - 24 months post-operatively. Subjects were questioned about the success of the surgery. Conditions were rated as improved or not improved.	Two subjects did not improve and were both from the deep posterior compartment group.	Not mentioned.
Schepsis & Lynch, 1998	16 subjects – (26 limbs) for anterior decompression and 12 subjects (20 limbs) for deep posterior decompression.	Surgical decompression (fasciotomy).	Follow-up of symptoms after four years.	15 out of the 16 subjects had excellent results for the anterior decompression. In 12 subjects (20 limbs) who underwent fasciotomy of the deep anterior compartment, there were five excellent, eight good, four fair and three poor results.	Not mentioned.

Table 2.8(b): Outcomes of surgical interventions during 1998 to 2002

Researchers	***Number of subjects***	***Intervention***	***Outcome measure***	***Results***	***Complications***
Howard *et al.*, 2000	62 subjects treated over a period of seven years.	Fasciotomy.	Questionnaire with regard to pain on VAS; level of improvement; level of maximum activity; satisfaction level and occurrence of re-operations.	A clinically significant improvement was reported by 81% anterior/ lateral compartment subjects and 50% subjects with deep posterior compartment involvement.	13% reported complication which included: haemorrhage, wound infection, nerve entrapment, swelling, artery injury, haematoma, lymphocele, peripheral cutaneous nerve injury and deep vein thrombosis.
Slimmon *et al.*, 2002	62 subjects in total. 50 subjects underwent a single operation.	Fasciotomy with partial fasciectomy of involved compartment.	Self- administered questionnaire, 51 months after surgery.	60% of the 50 subjects that underwent a single operation reported a reduced average pain and pain-on-running, although some still reported considerable levels of pain. 58% of the 62 subjects were exercising at lower intensities than before the surgery.	13 subjects out of the 62 said their symptoms reoccurred post-surgically or re-appeared in a different compartment.
Turnipseed, 2002	276 subjects.	Surgical procedures: open fasciectomy. Of the 436 treated compartments, 316 were anterio-lateral, 70 deep posterior and 50 superficial posterior.	Follow-up 60 months after surgery, inquiring about symptoms, daily or athletic activities.	92% had full relief of symptoms. 8% obtained symptomatic relief, but activity was limited because of new compartment symptoms.	Not mentioned.

2.3.2.9. Conservative management of chronic compartment syndrome

Since compartment syndrome of the posterior compartment occurs less frequently than compartment syndrome of the anterior and lateral compartments (Godon & Crielaard, 2005), the conservative outcomes of compartment syndromes in general will be reviewed.

The literature available on the conservative management of chronic compartment syndrome is limited. Most of the conservative approaches or modalities used in the management of CCS are only mentioned and not discussed in detail. The following list is a summary of the various conservative treatment modalities/ approaches mentioned in the literature and which will be discussed in this section:

- physical therapy (massage, ultrasound, stretching, heat, cold, myofascial release techniques, whirlpool, electrical stimulations). All of the physical therapy techniques were applied locally to the area of the posterior calf.
- orthotics, modification of shoes, taping
- anti-inflammatory medication, diuretics, steroid injections
- rest, cast immobilizations
- reduced training, different training programmes
- compression, elevation

Schepsis & Lynch (1998) state that once the patient has been diagnosed with chronic exertional compartment syndrome, the only worthy non-operative treatment is the modification of activity. They are of the opinion that if the athlete is unwilling or unable to give up the activity that causes the symptoms, the only other option is surgical decompression by fasciotomy. In their opinion other treatment modalities such as physiotherapy, rest, orthotics and anti-inflammatory medication are of minimal value.

Styf (1998) has investigated recurrent exercise-induced pain in the anterior aspect of the lower leg in 98 patients who were clinically diagnosed with chronic anterior compartment syndrome (CACS). Intra-compartmental pressure measurements confirmed the diagnosis of CACS in 26 of the patients. According to the subjective assessment done, all of the 98 patients tried various conservative treatment approaches including rest, reduced training, anti-inflammatory drugs, diuretics, modification of shoes, different training programmes and orthotic applications, as well as physiotherapy that included ultrasound therapy, stretching, local heat and cold. Conservative treatment approaches were only mentioned and not described in detail. According to the patients, none of the previously mentioned treatments had any lasting effect on their symptoms.

Davey *et al.* (1984) postulated that the tibialis posterior muscle is contained in its own osseofascial compartment and might be the site of isolated exertional/compartment syndrome. Part of the study was done on two runners complaining of pain to the posterior- medial aspect of the mid and lower third of the tibia. Both of these individuals had failed to respond to conservative modalities including rest, ice, anti-inflammatory drugs, physiotherapy, and foot orthoses. The conservative physiotherapy treatments were not described. The authors concluded that they have found true exertional compartment syndrome to be resistant to anything less than surgical decompression.

According to a study done by Detmer *et al.* (1985) on patients with chronic compartment syndrome, it was mentioned that:

- 41% had tried orthotics which was considered helpful by 15% of the patients;
- stretching programmes were widely used but were not considered helpful;
- 40% of the subjects underwent physiotherapy; and
- 49% of the subjects had used medication.

A third of the patients described the physiotherapy and the use of medication as being only somewhat helpful while the rest said that they had experienced no measurable relief of their symptoms.

In a study done by Martens *et al.* (1984) nine patients diagnosed with chronic compartment syndrome received conservative treatment consisting of prolonged rest, physiotherapy, anti-inflammatory drugs and stretching exercises of the flexor muscles of the lower leg. According to Martens *et al.* (1984), none of the conservative treatment methods led to an appreciable improvement. All the patients were forced to limit their sports activities to a certain extent and ended up undergoing a fasciotomy. Although the fasciotomy and its results were described in the study reported, conservative approaches were merely mentioned and not dealt with in any depth.

Martens *et al.* (1984) tried a variety of therapeutic modalities to treat the symptoms of shin splints (which they called medial stress syndrome). According to the authors, aspirin, phenylbutazone, heel-cord stretching, heel-pads and cast immobilizations did not have any lasting effect on the patients' symptoms.

Jackson & Bailey (1975) reported that taping or arch supports yielded no success in patients with CPCS and found that aspirin and local injection of steroids were also not beneficial.

According to Garcia-Mata *et al.* (2001), intermittent massage with specific stretching only serves to lengthen the time before onset of pain in patients with chronic exertional compartment syndrome, but does not cure or prevent the condition. The authors' mention the effect of massage together with specific stretches only in passing and then go on to describes surgery as a better option for the symptoms. Their study included 23 legs. Twenty-one patients complained of anterior compartment syndrome, one of posterior compartment syndrome and one of both anterior and posterior compartment syndrome.

Allen & Barnes (1986) have found with medial tibial syndrome (deep posterior compartment) that the outcomes of both surgical (fasciotomy of the medial border of the tibia) and conservative treatment (physiotherapy, steroid injections to the tibial border and shoe inserts) were poor. The physiotherapy techniques used, or their area of application were not mentioned.

Clanton & Solcher (1994) states, that conservative method for treating chronic compartment syndrome, such as ice, medication, shoe modification and orthotics usually provide little benefit. No further description is given with regard to the application of the conservative treatment methods.

According to Melberg & Styf (1989), 28 patients complaining of posterior-medial pain in the lower leg received conservative treatment, with no improvement in the signs and symptoms. The types or number of conservative treatments were not mentioned.

Poor results from non-operative treatment of chronic compartment syndrome were highlighted by Froneck *et al*. (1987) who reported that five out of seven patients were unable to return to sport after undergoing a conservative programme. The authors did not mention the type of non-operative treatment approaches that were used or the duration of the conservative programme.

Biedert & Marti (1997) have found conservative treatment techniques applied to patients with symptoms of CPCS such as anti-inflammatory medication, ultrasound therapy, myofascial release techniques, stretching and orthotics, not useful. This treatment was applied locally to the area of the lower leg but the number of treatments received by the patients was not mentioned. The authors mentioned the effect of these techniques only in passing and went on to describe the surgical management for CPCS.

A study done by Micheli *et al.* (1999) demonstrated that the conservative treatment of chronic compartment syndrome in young female athletes using treatment approaches such as ice, rest, compression, elevation, medication, ultrasound, orthotics, massage, whirlpool, heat, gel packs, electrical stimulation and stretching were not successful. Once again the number of treatments given to the patients was not mentioned.

Blackman *et al.* (1998) determined the effect of massage as a treatment on symptoms of chronic anterior compartment syndrome. The study was performed on seven patients, each receiving six treatments. Each massage session consisted of the following phases: preparatory massage (one minute), longitudinal gliding (one minute), transverse gliding (one minute), mobilizing digital pressure (two minutes) and myofascial release and posterior compartment massage (ten minutes). Between sessions they were given a stretching programme. Stretches were given for the anterior as well as the posterior compartment muscles. There was no significant difference in the three minute post-exercise compartment pressures after the treatment. There was however a significant increase in dorsi flexion work performed before the onset of pain following the massage (it is normally the plantar flexion action during running that leads to an increase in the intra-compartmental pressure whenever the posterior compartment is involved).

During 2002, Mouhsine *et al.* (2006) recruited 18 subjects for surgical release of the fascia after they have received, to no avail, conservative treatment for a mean period of four months. The conservative treatment entailed modification of exercise programmes, stretching, changing of shoes, shoe inserts, and local injections of xylocaine into the area of maximum swelling. Although the reviewed studies all had poor outcomes, it is difficult to evaluate the effect of manual therapy and other physiotherapy techniques on CCS because in none of the studies neither the type and application of the conservative techniques/approaches used, nor the number of treatments were described in detail.

2.3.3. Functional anatomy and biomechanical factors

In the literature a number of researchers found a correlation between exercise related leg pain (ERLP) and biomechanical factors (Bennett *et al*., 2001; Dugan & Bhat, 2005; Hreljac, 2005). Dugan & Bhat (2005) found that foot pronation had a distinct influence on the development of ERLP in athletes. They found that athletes with a history of ERLP had a significant greater foot pronation than athletes without such a history. Excessive pronation is however difficult to define due to the fact that the magnitude of normal foot pronation in a large sample of asymptomatic subjects has never been described (Johanson *et al*., 1994).

Although some research findings contradicts these relationships (Johanson *et al.*, 1994; Lun *et al.*, 2004), these contradictions are probably contributable to the definition of runners and the associated distances run by the different research populations (Hreljac, 2005). Hreljac (2005) however makes a convincing argument for such a correlation based on the increased risks for injury due to increased torque and instability that results from improper biomechanical alignments.

In the following section the function of the muscles of all the compartments of the posterior compartment of the lower leg will be discussed in the light of the effect which they have on movement patterns which will be assessed during the gait analysis.

2.3.3.1. Muscles of the posterior compartments of the lower leg

In order to determine which muscles are involved and play a role in the cause or the perpetuation of the symptoms of CPCS, it is necessary to analyse the functions of the muscles contained in the posterior compartment of the lower leg.

As previously seen, the deep posterior compartment contains the flexor digitorum longus (FDL) -, the flexor hallucis longus (FHL) - and the tibialis posterior muscle. The main function of the FDL is to flex the distal phalanx of each of the four lesser toes and the main function of the FHL is to flex the distal phalanx of the great toe (Agur, 1991). Both of these muscles also assist in plantar flexion (PF) and inversion (Inv) of the foot when the foot is free to move (Travell & Simons, 1999). The FDL and the FHL muscles are also important in preventing extreme plantar to dorsi flexion movement at the metatarsophalangeal joints when the foot is in contact with the ground. An inflexible shoe sole might prevent normal extension of the metatarsophalangeal joints during running. The stiffness of the sole effectively lengthens the lever arm against which these two long flexor muscles of the toes function, and thus overload them. An inflexible shoe sole might thus be one of the factors perpetuating the symptoms of CPCS if the FHL and the FDL muscles are involved (Travell & Simons, 1999).

The FDL and the FHL stabilize the foot and ankle in the mid- to late-stance phase of the running gait, playing a role in the medio-lateral balance. These muscles also assist other plantar flexors in enabling the individual to transfer weight to the fore foot and they assist in the maintenance of equilibrium when the weight is on the fore foot (Travell & Simons, 1999).

FHL stenosing tenosynovitis is a well-recognised dysfunction amongst ballet dancers and is also occasionally seen in runners. The symptoms typically begin insidiously and include pain and tenderness in the posterior-medial area of the ankle (might radiate distally along the medial arch). Passive and or active ankle and or hallux movement is painful and a crepitus of the hallux might be present. Weight-bearing exercises exacerbate the symptoms and swelling may be seen in the vicinity of the postero-medial part of the ankle (Oloff & Schulhafer, 1998).

In summary, the following factors need to be assessed in order to determine whether FHL- and the FDL muscle play a role in the symptoms of CPCS:

- muscle strength of the distal phalanxes of the toes;
- the amount of plantar and dorsi flexion range of movement at the metatarsophalangeal joints when the foot is in contact with the ground;
- the medio-lateral balance in the mid- to late-stance phase; and
- the maintenance of equilibrium when the weight is on the fore foot.

After heel contact, the tibialis posterior acts as a shock absorber for the subtalar joint limiting hind foot eversion by eccentric contraction (Mosier *et al.*, 1999). During mid-stance, contraction of tibialis posterior muscle causes inversion of the subtalar joint, locking the calcaneocuboid and talonavicular or transverse tarsal joints. This results in a rigid lever for forward propulsion of the foot over the metatarsal heads (distributes the body weight over the heads of the metatarsals). With dysfunction of the tibialis posterior muscle, there is no rigid lever during the mid-stance, resulting in decreased tarso-metatarsal joint stability and hind foot inversion. The forward propulsion force of the gastrocnemius and soleus muscle complex acts at the mid-foot rather than at the metatarsal heads, creating excessive mid foot stress allowing increased mid foot abduction (Mosier *et al.*, 1999).

When the foot is free, the tibialis posterior muscle acts to invert and to adduct the foot. It also assists in plantar flexion of the ankle joint (Travell & Simons, 1999). Tibialis posterior dysfunction is associated with an increased amount of fore foot abduction, mid-foot collapse and excessive hind foot valgus (Mosier *et al.*, 1999). Excessive hind foot valgus causes an increase in tensile stress to the plantar fascial insertion. During the initial stages of tibialis posterior muscle dysfunction, pain will be experienced along the course of the tibialis posterior tendon (Travell & Simons, 1999; Agur, 1991). In summary, with regard to the possible involvement of the tibialis posterior muscle as a role player in the symptoms of CPCS, the following need to be assessed:

- signs of mid foot collapse
- increased fore foot abduction
- increased hind foot valgus

The superficial posterior compartment contains the gastrocnemius, the plantaris and the soleus muscles. The soleus muscle is a primary plantar flexor of the foot (Travell & Simons, 1999). A study done by Michael & Holder (1985) has shown that the medial one-half of the soleus muscle is also an inverter of the calcaneus. The soleus muscle has a tough aponeurotic covering both anteriorly and posteriorly of the muscle. This fascia, which is firmly attached to the anterior and the posterior surfaces of the soleus muscle, fuse together beyond the edge of the muscle and form an impressively tough attachment to the medial border of the tibia, much stronger than the thin layer of fascia covering the deep layer of muscles. The soleus and its fascia form an unyielding structure under which the deep muscles must function (Michael & Holder, 1985).

An injured soleus muscle can produce pain along the medial border of the tibia. This referred pain was thought to originate from the tibialis posterior muscle (O'Donoghue, 1976), but Michael & Holder (1985) showed that the tibialis posterior muscle takes its origin a considerable distance away from the medial border of the posterior tibia and that the muscle belly of the tibialis posterior muscle is higher in location than the usual site where the pain is experienced. The tendinous portion of the soleus makes up the anterior one- half of the Achilles tendon in association with the gastrocnemius, and as the Achilles tendon approaches the calcaneal insertion, it rotates 90 degrees so that the soleus contribution to the tendon inserts on the medial one-third of the calcaneus, while the gastrocnemius contribution inserts in the lateral two- thirds. From a biomechanical standpoint, the insertion of the soleus muscle on the medial aspect of the calcaneus makes it vulnerable to excessive elongation when the heel is placed in the pronated position (Michael & Holder, 1985) (See Figure 2.4).

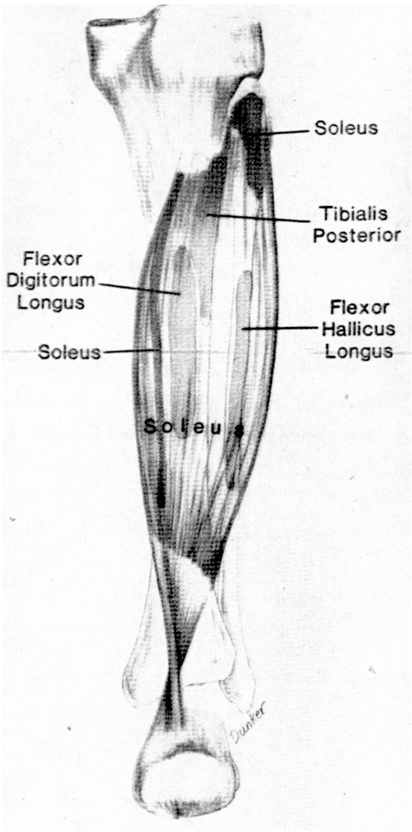

Figure 2.4: Rotation of the Achilles tendon (Michael & Holder, 1985)

In summary, with regard to the possible involvement of the soleus muscle in the symptoms of CPCS, the following factors need to be assessed:

- tightness of the soleus bridge over the deep posterior compartment
- hind foot pronation (Achilles tendon angle)

The gastrocnemius muscle is most effective as a plantar flexor at the ankle when the knee is extended. As the knee becomes progressively more flexed this muscle loses effectiveness and plantar flexion of the foot is accomplished increasingly by the soleus muscle. The gastrocnemius muscle may also assist flexion at the knee. As proposed by Travell & Simons (1999), the gastrocnemius muscle is not likely to play a role in the cause or perpetuation of symptoms of CPCS.

2.3.3.2. Muscles of the anterior compartments of the lower leg

The anterior compartment contains the tibialis anterior- (TA), the extensor hallucis longus (EHL)-, the peroneus tertius- (PT) and the extensor digitorum longus (EDL) muscles. The tibialis anterior muscle can give rise to pain superficially over the big toe. During running, the function of the tibialis anterior muscle is to dorsi-flex the foot of the non-weight bearing leg at the talocrural joint and to supinates (inverts and adducts) the same foot at the subtalar and transverse tarsal joints. It is not active as an inverter during plantar flexion (Travell & Simons, 1999). With weakness of the tibialis anterior muscle, a person might have difficulty in clearing the foot during the swing phase (Travell & Simons, 1999). The PT muscle causes dorsi-flexion and assists with eversion (Agur, 1991; Travell & Simons, 1999.).

The EDL acts to dorsi-flex and evert the foot and to extend the four lesser toes. A heel strike position with the calcaneus in a position of too much inversion might therefore be an indication of a weak PT- or EDL muscle. The EHL assists in dorsi-flexion and inversion of the foot and extends the big toe. The EDL- and the EHL muscles functions as assistants in controlling (decelerating) the descent of the fore foot to the floor immediately following heel-strike, thereby preventing foot slap. During the swing-phase, they assist in providing foot-floor clearance. The EDL muscle help to provide a pure dorsi-flexion movement of the foot by balancing the inversion pull of the tibialis anterior muscle. With a weakened EDL muscle, the calcaneus might move into a position of inversion (Travell & Simons, 1999).

2.3.3.3. Muscles of the lateral compartments of the lower leg

The lateral compartment contains the peroneus longus- (PL) and the peroneus brevis (PB) muscles. They cause the foot, when free, to abduct and to evert. These two movements together cause pronation. Both the muscles also assist plantar flexion and together with the tibialis posterior – and the FDL muscles, it helps to control medio-lateral balance in walking (Travell & Simons, 1999).

In conclusion, the following measurable factors will be considered as possible role players in the precipitation or perpetuation of symptoms of CPCS and will therefore be taken into account during the individual assessments:

- muscle strength of the muscles in the lower leg;
- tightness of the soleus bridge over the posterior compartment; and

- during running the degree of forefoot abduction, the alignment of the Achilles tendon angle and movement patterns, e.g. the position of the calcaneus during heel strike and the ability to clear the foot easily during the swing phase will be observed.

2.3.3.4. Normal running gait

In order to identify abnormal movement components and compensatory mechanisms, which is often seen clinically in subject with symptoms of CPCS, it is necessary to analyse and compare the subjects' gait to what is considered as the norm for symptom free runners. From a biomechanical perspective, various types of pathology in the musculoskeletal system can alter mobility and muscular effectiveness in such a way that subjects substitute and develop compensatory mechanisms. This results in a walking/running pattern which is a combination of normal and abnormal movement patterns which increases the energy costs of running and compromises the functional versatility of the walker/runner (Perry, 1992). Running is similar to walking, but there are differences that need to be examined. Running requires greater balance, muscle strength, and range of motion than normal walking. Greater balance is required because running is characterized not only by an absence of double support periods observed in normal walking but also by the presence of float periods in which both feet are out of contact with the supporting surface (Levangie & Norkin, 2001). Walking/running is a complex activity because it is dependent on a series of interactions between two multi-segmental lower limbs, the trunk and the upper limbs. Normal walking/running gait repeats a basic sequence of motions that serve to progress the body along a desired path while maintaining weight-bearing stability, conserving energy and absorbing shock during ground contact. A gait cycle is defined as the time from heel strike to ipsilateral heel strike. Each gait cycle is divided into two periods, stance and swing. To facilitate observational analysis, the walking/ running gait cycle is further divided into eight phases, namely: initial contact; loading response; mid-stance; terminal stance; pre-swing; initial swing; mid-swing and terminal swing. For each of these phases, the movement components taking place at the pelvis, the hips, the knees, the ankles and the feet must be analysed (Perry, 1992). The walking gait analysis of Perry (1992) will be applied for the gait analysis of the runners. This is summarized in Table 2.9.

Table 2.9: Sequence of movement at the pelvis, hips, knees, ankles and feet during running (Perry, 1992)

	Weight acceptance		***Single leg support***		***Swing leg advancement***			
Joint	Initial contact.	Loading response.	Mid stance.	Terminal stance.	Pre-swing.	Initial swing.	Mid-swing.	Terminal swing.
Pelvis	Anterior rotation.	Anterior rotation.	Neutral.	Posterior rotation.	Posterior rotation.	Posterior rotation.	Neutral.	Anterior rotation.
Hip	Flexion.	Flexion.	Neutral.	Extension.	Slight extension to neutral.	Flexion.	Flexion.	Flexion.
Knee	Neutral to slightly flexed.	Flexion.	Extended, but not completely.	Extended, but not completely.	Flexion.	Maximum flexion.	Less flexion.	Neutral.
Ankle	Neutral.	Plantar flexion.	Dorsi flexion.	More dorsi flexion.	Plantar flexion.	Less plantar flexion.	Neutral.	Neutral.
Subtalar		Pronation.		Gradual progression to inversion.	Neutral.			

Observational gait analysis is used to some extent by all health care professionals. It is the easiest and least expensive method of analysis. The gait cycle is observed with gross focus sequentially on stance, swing and float phase. The simplest form of motion analysis is the use of video-recording (Dugan & Bhat, 2005).

The risk factors for developing running injuries depend on a number of extrinsic factors such as velocity, training time, equipment (shoes) and running surface. Intrinsic factors such as the individual's physical characteristics and personality traits can also influence the likelihood of injury. The factors most associated with running related injuries of the foot and ankle include anatomical or biomechanical abnormalities, lack of flexibility (tightness in the gastrocnemius- and soleus muscles which can cause compensatory excessive pronation of the hind foot), poor strength or muscular imbalances, the type of shoe or orthotics used and type of running surface that the runner trains on (Hintermann & Nigg, 1998; Reinking, 2006).

Excessive eversion velocity has been associated with medial tibial stress syndrome (Viitasalo & Kvist, 1983). Excessive pronation of the hind foot will predispose individuals to injuries on the medial aspect of the lower extremities. Increased pronation is associated with injuries such as medial tibial stress syndrome, tibialis posterior tendonitis, bursitis of the tendon Achilles (or tendonitis), patello-femoral disorders, iliotibial friction syndrome and lower extremity stress fractures. However, specific anatomic abnormalities and abnormal biomechanics of the lower extremity are not correlated with specific injuries on a predictable basis (Hintermann & Nigg, 1998). In runners with excessively pronated hind feet, the muscles of the superficial and deep posterior compartments are required to contract harder and longer eccentrically to resist pronation after heel strike. At toe off, they work harder concentrically to accelerate supination. As fatigue sets in, these muscles fail to provide the normal degree of shock absorption which might lead to the development of stress fractures, teno-periostitis or compartment syndrome (Brukner, 2000). According to Brukner (2000), abnormal biomechanics is a major cause of injuries to the bone, periosteum and muscle. Biomechanical events occurring at the lower limb at the time of initial ground contact include shock absorption, joint stabilization of the pelvis, the hip, knee and ankle joints as well as foot flexibility.

Tight calf muscles will also restrict ankle dorsi-flexion and increase the tendency for excessive pronation, leading to increased internal rotation of the tibia (Brukner, 2000). According to Hintermann & Nigg (1998), a combination of excessive pronation and substantial movement transfer of foot eversion into internal tibial rotation is a better predictor of the development of overuse injuries than excessive pronation alone (the transfer will be small for individuals with low arches and high for those with high arches). The tibialis posterior muscle also seems to play a significant role in stabilizing the arch of the foot and as such in controlling the pronation movement at the ankle joint complex (Travell & Simons, 1999).

In summary it is clear that it is important to take biomechanical factors (intrinsic factors), which might play a role in the precipitation and perpetuation of the injury into account, when treating an injury such as CPCS. Based on the literature, it thus seems as though the following biomechanical factors should be taken into account when assessing the patient: dynamic pes planus, restricted ankle dorsi-flexion, increased hind foot inversion and the amount of internal tibial rotation (and the factors that might influence this). It is also important to bear in mind the extrinsic factors that might play a role in the presentation of symptoms of chronic compartment syndrome, namely shoes, training surfaces and intensity of training.

Since it seems as though most authors see excessive pronation as a role player in the precipitation and perpetuation of injuries, it becomes important to find an objective way of measuring the amount of pronation. A simplistic method of measuring the amount of hind foot pronation was proposed by Gould & Davies (1985); Johanson *et al.* (1994) as well as Hunt (1998). Subtalar joint eversion and inversion were determined with the subject positioned prone and the lower half of the calf off the edge of the plinth. Sliding callipers were used to identify midpoints on the calf and calcaneus, and lines were drawn along the midline on the posterior third of the calf and on the calcaneus. The axis of a standard goniometer was places between the malleoli in the frontal planes. The stationary arm of the goniometer was placed over the line on the posterior calf, and the movable arm was placed over the line on the posterior calcaneus.

Hind foot over pronation accounts for, or is associated with, approximately 10% of all running injuries (Hintermann & Nigg, 1998). The normal degree of hind foot pronation varies between 6° and 12º (Hoppenfield, 2000). Hind foot over pronation, according to measures provided by Clarke *et al*. (1984), is defined as a pronation angle of more than 12º measured during running. None of the aforementioned however provided any information with regard to the standard deviation. Brukner & Khan (2007) indicated that fascia related injuries such as iliotibial band syndrome; shin splints and plantar fasciitis are all associated with an increased degree of hind foot pronation.

Brukner & Khan (2007) proposed that injury of connective tissue leads to an inflammatory response. This is followed by repair with scar tissue which could, if not subjected to the necessary forces during the healing period, result in irregular arrangement of fascia. This could cause restrictions and a compromise in the effective length of the fascia, which results in pain or malfunctioning throughout the body. Manheim & Lavett (1989) are of the opinion that tight fascia leads to abnormal biomechanics.

Soft tissue mobilizing techniques, such as myofascial release techniques (Manheim & Lavett, 1989), trigger point therapy (Travell & Simons, 1999) and specific soft tissue mobilizing techniques (Hunter, 1998) allow therapists to treat soft tissue dysfunctions. The ultimate goal of soft tissue mobilizing techniques is optimal body alignment, which allows for the most efficient use of energy for daily tasks (Barnes, 1990). Optimal body alignment will also facilitate normal movement patterns and normal biomechanics.

In terms of the modified theoretical framework for the pathogenesis of CPCS that was developed and discussed in Chapter 2, one can argue that the stresses that are induced in the fascial web as a result of restricted fascial movement in the clinical significant muscles, would also have an effect on the alignment of the feet with the rest of the body. It was thus decided to investigate the effect of the soft tissue mobilization of the clinical significant muscles in subjects with abnormal pronation. From the literature, abnormal pronation appears to be in excess of 12°. The normal degree of hind foot pronation which varies between 6° and 12º (Hoppenfield, 2000), thus implies an average of around 9º.

2.3.3.5. Dorsi flexion at the ankle joint

As previously stated, tight calf muscles will also restrict ankle dorsi-flexion and increase the tendency for excessive pronation. It therefore becomes important to measure the degree of dorsi flexion at the ankle. Markings need to be made on the lateral side of both ankles. Dots can then be made over the central part of the inferior border of the lateral malleolus and on the lateral side of the foot over the head of the fifth metatarsal bone. Another dot must be made over the tibia-fibular joint and the centre of the lateral malleolus. Thereafter, the subject must run barefoot on a treadmill with a calibrated running speed of 7.6 km/h, whilst being videotaped with a Sony digital video camera. This video material must then be copied to a specific software program (TV 2000 combined with Corel Draw version 11) in order to measure the degree of dorsi flexion at the ankle. The dots over the head of the fifth metatarsophalangeal joint and inferior border of the lateral malleolus must be joined with a straight horizontal line through Coral Draw. The dots over the centre of the lateral malleolus and the tibia-fibular joint must be joined with a straight vertical line using Corel Draw. Every measurement must be taken three times at different intervals of the mid and terminal stance of the running gait to calculate an average value.

The fact that the surgical release of fascia currently provides the only relative successful management of symptoms of CPCS, emphasizes the important role that non-compliant compartment fascia plays in the symptoms thereof. Since no study with positive outcome of conservative treatment aimed locally at the area of the symptoms could be found in the literature (Jackson & Bailey, 1975; Davey *et al.*, 1984; Martens *et al.*, 1984; Detmer *et al.*, 1985; Allen & Barnes, 1986; Froneck *et al.*, 1987; Melberg & Styf, 1989; Clanton & Solcher, 1994; Biedert & Marti, 1997; Blackman *et al.*, 1998; Schepsis & Lynch, 1998; Styf, 1998; Micheli *et al.*, 1999; Garcia-Mata *et al.*, 2001), the next logical step was to explore the literature on the current knowledge on fascia and its characteristics.

2.4. KNOWLEDGE OF FASCIA

2.4.1. Composition of normal fascia

The word "myofascial" connotes the bundled together, inseparable nature of muscle tissue (myo-) and its accompanying web of connective tissue (fascia) (Comerford, 2000; Myers, 2001). Any soft tissue mobilizations will therefore involve both the muscle and the fascia (myofascia) and various soft tissue mobilizing techniques such as trigger point release techniques (Travell & Simons, 1999), myofascial release techniques (Barnes, 1990; Manheim, 1994) and specific soft tissue mobilizing techniques (Hunter, 1998) will be used to mobilize the soft tissue.

Fascia is composed of connective tissue (CT). Schultz & Feitis (1996) have proposed that the organization of connective tissue in the leg is different from that of the arm. In the leg the connective tissue is structured for stability and in the arm it is more elastic for flexibility. In the forearm the interosseous membrane needs to be elastic so that the bones can rotate with the multidirectional use of the hand. In the lower leg, the interosseous membrane must be denser to support the leg and control rotation between the tibia and the fibula as the foot moves (Schultz & Feitis, 1996).

The properties of CT are determined by the amount, type and arrangement of the extracellular matrix (ECM). The ECM consists of three major types of macromolecules namely fibres, proteoglycans (PGs) and glycoproteins. The two most important fibrous components of the ECM are collagen and elastin, both insoluble macromolecular proteins. The striking feature of the most prominent collagens is their ability to resist tensile loads. Generally they show minimal elongation under tension and a part of this "elongation" is due to the straightening of fibres that are packed in various three-dimensional arrays (Culav *et al.*, 1999). Collagen fibres are coiled and their inter weaving allows for elastic displacement and return. When these fibres are densely matted or not aligned in the direction of movement, their elastic potential is dispersed. This is the case where there is thickening or bunching of the connective tissue (Schultz & Feitis, 1996). An increase in fascial thickness was found during biopsies in subjects diagnosed with CCS (Detmer *et al.*, 1985; Hurschler *et al*., 1994 and Garcia-Mata *et al*., 2001).

The second major component of the ECM is the PGs. Their mechanical functions include hydration of the matrix, stabilization of collagen networks and the ability to withstand compressive forces. The mechanical properties of CT such as the ability to resist tension, compression, extensibility and torsion are determined by the proportions of the matrix components. Generally, tissues with high collagen-fibre content and low amounts of PG resist tensile forces and those with high PG content, combined with a network of collagen fibres, withstand compression (Culav *et al.*, 1999).

Dense regular CT is a histological category of CT that includes ligaments, tendons, fascia and aponeuroses. As described above, these dense CT structures all share similar elements but differ in mechanical characteristics, primarily because of the arrangement and various proportions of their basic constituents. Facia has collagen bundles, but the bundles are organized into multilayered sheets or lamellae. The bundles within individual layers are roughly parallel but often have some undulations or waviness. Adjacent layers may not have the same fibre direction, although fibres will often pass between adjacent layers as well as into adjacent loose CT. Ground substance and elastin content is low in fascia (Threkeld, 1992) and fascia is therefore classified as mainly non-elastic (Brukner, 2000).

According to Schwind (2006), the proportion of collagen and elastin fibres within any area of fascia depends upon the functional demands placed upon the tissue in that area. If there are strong tensile stresses on the tissue, then the collagen portion will predominate and there will be less elastic fibres. In the periphery, such as the lower limb, where potentially dangerous forces are greatest, the fascia tends to be thicker and denser. When the work load is heavy, thickened fascia can completely replace muscle bundle e.g. the iliotibial tract and the lumbosacral aponeurosis (Paoletti, 2006).

The function of fascia is to constrain muscles to a specific area and to protect muscles. Fascia prevents muscles from tearing and also prevents muscle hernias. If muscles were not surrounded by fascia, their action would be uneven and uncoordinated and would rupture and tear more easily. Without the structural protection of the fascia, the ability of the muscle to generate and transfer power and movement would be limited

(Robertson, 2001). In a study done by Huijing & Baan (2001), muscles within the anterior tibial compartment and within the peroneal compartment were excited simultaneously and maximally, first, with the anterior compartment intact, second, after a blunt dissection of the anterior and the lateral interface of extensor digitorum longus- and tibialis anterior muscles, thirdly, after a full longitudinal fasciotomy of the anterior tibial compartment and finally, after full removal of tibialis anterior- and extensor hallucis longus muscles. It was found that the length-force characteristics were significantly changed by these interventions. Blunt dissection caused a force decrease of approximately 10% at all lengths. This indicates that intermuscular connective tissue mediates significant interactions between adjacent muscles. A full lateral compartmental fasciotomy increased optimal length and decreased active slack length, leading to an increase of length range (by approximately 47%), while decreasing optimal force. Based on these results, they concluded that extra muscular connective tissue has a sufficient stiff connection to intramuscular connective tissue to be able to play a role in force transmission.

Every muscle of the body is surrounded by a smooth fascia sheath, every muscular fascicle is surrounded by fascia, every fibril is surrounded by fascia, and every micro-fibril down to the cellular level is surrounded by fascia (Barnes 1990). Therefore fascia plays a key role in length and function of the muscular component. The word “myofascial” connotes the bundled together, inseparable nature of muscle tissue (myo-) and its accompanying web of connective tissue (fascia) (Comerford, 2000; Myers, 2001).

In summary, patients with CT problems affecting movement are frequently examined and treated by physical therapists. Knowledge of the CT matrix composition and its relationship to the biomechanical properties of these tissues, particularly the predictable responses to changing mechanical forces, offers an opportunity to provide a rational basis for treatments. The complexity of the interplay among the components, however, requires that further research be undertaken to determine more precisely the effects of treatments on the structure and function of CT (Culav *et al.*, 1999).

2.4.2. Manual therapy techniques for connective tissue dysfunction

Connective tissue problems can be caused by CT shortening or by diminished CT mobility (Threkeld, 1992). Since the CT is responsive to changes in the mechanical environment, both naturally occurring and applied (Culav *et al.*, 1999), the following soft tissue mobilizing techniques can be used by physical therapists in order to effect the healing of the CT, following injury:

- specific soft tissue mobilization (Hunter, 1998)
- myofascial release techniques (Manheim, 1994)
- trigger point release techniques (Travell & Simons, 1999)

The actual mechanism responsible for the symptoms of CCS is unclear. It has however been speculated that the process of CCS may result from repeated micro injury to the involved compartment (Ross, 1996). According to the proposed pathogenesis of CPCS as illustrated by Clanton & Solcher (1994) micro tears are caused by the increase in the intra-compartmental pressure. Therefore subjects with symptoms of CPCS are normally seen during the mechanical or remodelling phase of healing. The objective during this stage is to restore the biomechanical properties of the tissue as close as possible to normal by the formation of a functional scar. A functional scar is a scar in which the collagen tissue is formed in the same line as the tissue it is replacing and the scar tissue is as long as the tissue it is replacing. It is not adhered to any adjacent tissue and is of sufficient quality and quantity to accept the compressive, distracting and shearing stresses to which it will be subjected. It must be able to shorten, lengthen and move in relation to its surrounding tissues (McGonigle & Matley, 1994).

If cross link formation is responsible for a degree of stiffness, mobilization techniques should be applied far enough into resistance to disrupt the cross link formation in order to produce change (Hendricks, 1995). Specific soft tissue mobilizations according to him can be used to disrupt the cross link formation. These techniques apply a longitudinal stretch to the tissue by exerting a manual force applied at 90° to the soft tissue. It is applied transversely to the line of collagen fibres but in the same plane as the fibres. The force is increased into resistance and applied for 3 x 60 seconds. The techniques should be followed up with stretches done by the subject, each stretch lasting 30 seconds (Hunter, 1998).

Myofascial release techniques can be used to lengthen shortened CT as well as to disrupt cross links. The aim of myofascial release techniques is to break up any cross restrictions and to restore the ground substance to its normal viscosity. Manheim (1994) is of the opinion that any myofascial restriction at, near or far from a target muscle causes distortions not only in the target muscle but in other muscles as well. She is therefore of the opinion that all myofascial restrictions must be treated and released to restore proper alignment and energy efficient movement to the entire system. When the location of the fascial restriction is determined, gentle pressure is applied in its direction. This has the effect of pulling the elasto-collagenous fibres straight. When pressure is first applied to the elasto-collagenous complex, the elastic component is engaged. This has a springy feel. The elastic component is slowly stretched until the hands stop at a firm barrier. This is the collagenous component. This barrier cannot be forced; it is too strong. Instead, gentle sustained pressure will release it. This fact has to do with viscous flow phenomenon, that is, a low load (gentle pressure) applied slowly will allow a viscous medium to flow to a greater extent than a high load (quickly applied pressure). By increasing the viscosity of the ground substance this allows the collagen fibres to rearrange themselves resulting in increased tissue length (Barnes, 1990). The physical therapist follows the motion of the tissue, barrier to barrier, until freedom from abnormal restriction is felt (Barnes, 1990).

Trigger point therapy is another form of myofascial release that is proposed to cause a change in tissue length by allowing the involved muscle to lengthen fully. Travell & Simons (1999) define a myofascial trigger point as a hyperirritable locus within a taut band of skeletal muscle, located in the muscular tissue and/ or its associated fascia. A trigger point prevents full lengthening of the muscle and weakens the muscle. The spot is painful on compression and can evoke characteristic referred pain and autonomic phenomena. The relaxed muscle is stretched to the verge of discomfort, where after a tolerable, painful pressure is exerted on the trigger point. When the pain starts to abate, the pressure is increased until the subject does not experience the pain anymore. According to these authors normal muscles do not contain trigger points.

2.4.3. Reflection

As stated the actual mechanism responsible for the symptoms of CCS is unclear, but it has been speculated that the process may result from repeated micro injury to the fascia (Ross, 1996). Eisele & Sammarco (1993) have found that the muscle within a compartment may undergo a 20% volumetric increase. If the compartment margins are unable to accommodate this increase in size, they may be stretched and injured. Each stretching trauma results in inflammation which, as it resolves, contributes to scarring. Because scar tissue tends to contract as it matures, this could decrease the compartment size and further contribute to the compartment's inability to accommodate volumetric enlargement during the next exercise bout. The other possibility is that the scar tissue may hypertrophy, causing it to become thicker and less elastic (Hutchinson & Ireland, 1994). This will further prohibit its ability to compensate for changes in compartmental volume (Ross, 1996). There are research reports that support this explanation in that the fascial tissue from compartments with CCS was demonstrated to be thicker than normal (Detmer *et al.*, 1985).

As mentioned (in section 2.14), the arrangement of the fascial fibres, allows a certain amount of deformation of viscous connective tissue. With injury, as discussed above, together with the formation of adhesions (macro structure), the arrangement of the fibres has been changed and this might affect the amount of deformation/ length that was available. When these fibres are densely matted or not aligned in the direction of movement, their elastic potential is dispersed (Culav *et al.*, 1999). This could be the case where there is thickening or bunching of the fascial connective tissue (Detmer *et al.*, 1985; Hurschler *et al.*, 1994; Schultz & Feitis, 1996; and Garcia-Mata *et al.*, 2001). Fascial thickening develops as a response to forces of tension and mechanical demands on the fascia during running. Hurschler *et al.* (1994) have found that fascia samples removed from the affected compartment of a patient who has been diagnosed with CPCS were thicker and structurally stiffer in the axial direction compared to fascia from a normal compartment.

The problem appears to be self-perpetuating, as the tissues have insufficient extensibility (decrease in the effective functional length of the myofascial system) to allow the desired movement to take place and pain is produced when the tissue is overstretched (as what happens during running). This triggers the whole inflammatory response again. This result in further thickening and the formation of adhesions at tissue interfaces (Holey, 1995).

The healing of fascia (type 1 connective tissue), following injury, follows the same classic sequence of inflammation, repair and remodelling as found with other soft tissue injuries. Fascia shrinks when it is inflamed and is slow to heal because of a poor blood supply; it is a focus of pain because of its rich nerve supply (Manheim, 1994). However, micro-structurally, the end results of the healing / reorganizing process in connective tissue is that the tissue:

- has a more irregular arrangement (the arrangement and the alignment are a result of the mechanical stresses applied to the tissue);
- has lower water content; and
- contains more random cross-links between fibres, fibre bundles and adjacent tissues.

As the collagen fibres are more randomly aligned with respect to forces applied to the tissue, the fibres must resist forces that are not parallel to their longitudinal axes. This is a task for which collagen is not structurally designed. In addition the loss of water diminishes the ease with which the collagen bundles might slide past one another (Threkeld, 1992).

From the literature it can thus be concluded that fascia, in the normal healthy state, is relaxed and wavy in configuration. It has the ability to move without restriction. When connective tissue experiences physical trauma, scarring or inflammation, the fascia loses its pliability. It becomes tight, restricted and a source of tension to the rest of the body. Trauma, such as repetitive strain injuries, has accumulative effects. The changes which trauma causes in the fascial system influences comfort and the functioning of the body. Fascia is a non-elastic, integrated network, where collagen fibres are coiled and their interweaving allows for elastic displacement and return. Fascia shrinks when it is inflamed and is slow to heal because of a poor blood supply. Fascia of affected compartments in CPCS was demonstrated to be thicker and structurally tighter in the axial direction compared to fascia removed from a normal compartment. Myofascial release techniques, specific soft tissue mobilizations and trigger point therapy are proposed to cause a change in tissue length, by rearranging the collagen fibres that occurs in the tissue in response to the viscoelastic effects of the techniques. The release of an active trigger point also causes a change in tissue length by allowing the involved muscle to lengthen fully. Myofascial release techniques and specific soft tissue mobilization techniques can be used to disrupt cross link formations. Conservative treatment of the local fascial sheath and contained muscles has to date not been very successful in alleviating the symptoms of CPCS.

Surgical release for compartment syndrome has demonstrated moderately good results, but could have several disadvantages. Several factors affecting normal gait and running patterns are indicated by the literature as possible role players in the symptoms of CPCS. These include tightness of the calf muscles, muscle strength of flexion of the distal phalanxes of the toes, the degree of plantar and dorsi flexion range of movement at the metatarsophalangeal joints when the foot is in contact with the ground, the medio-lateral balance in the mid- to late-stance phase, the maintenance of equilibrium when the weight is on the fore foot, an increased amount of fore foot abduction, hind foot valgus and a greater than normal Achilles tendon angle. It also includes external factors such as training time, shoes and running surfaces.

The development of the methodology for the management of the case studies to follow will be based on the aforementioned literature review and will be discussed in the next chapter. The major discrepancies found in the literature research that will be addressed are:

- the lack of success with conservative treatment and
- that the conservative treatments are not aimed specifically at the fascia that plays a crucial role in the condition as determined through the literature research.

2.5. THE CONTINUITY OF THE SOFT TISSUE LINKS

2.5.1. Introduction

This section deals with an extension of the literature research based on the findings of the first three case studies. The interventions had better results with the application of the intervention techniques to areas external to the calf area. The application of the treatment techniques applied distally, further proximally, as well as anteriorly from the posterior compartment, showed positive results in terms of the outcome measures which were elected, i.e. the intensity of pain and the ability of the subject to run. It was then argued that if the soft tissue mobilization of the posterior compartment had no positive effect, the fact that the treatment of the more proximal and anterior soft tissue led to a reduction in the pressure in the posterior compartment, then the soft tissue of the calf muscles must be linked to these posterior muscles in order to have an effect on the symptoms. Based on this argument it was decided to do an additional literature research in order to establish whether such anatomical links between the calf muscles and the more proximal anterior and posterior myofascial structures existed.

As indicated in Chapter 1, little effective research results emerged on myofascial related issues after the “classic” work done by Travel and Simons (Harden, 2007). The results that emanated from this research make a major contribution in the sense that it provides the first focussed perspective on the anatomical links between the calf muscles and the myofascial structures and associated muscle interdependencies that exist. These interdependencies between the more proximal muscles and myofascial structures allow for the development of successful treatment interventions for the symptoms of CPCS external to the problem. The resulted form the literature research which follows, provides the first comprehensive identification of the interdependencies of muscles linked to the myofascial tissue of the posterior compartment. The progressive development of these links is discussed in the following sections. The final integrated perspectives of these links are covered in Chapter 4 which deals with research results.

2.5.2. Description of the myofascial links

As discussed in the previous section, every muscle of the body is surrounded by a smooth fascia sheath, every muscular fascicle is surrounded by fascia, every fibril is surrounded by fascia, and every micro- fibril down to the cellular level is surrounded by fascia (Steffen, 1996). The word “myofascial” connotes the bundled together, inseparable nature of muscle tissue (myo-) and its accompanying web of connective tissue (fascia) (Comerford, 2000; Myers, 2001). Anatomical links found between the calf muscles and the more proximal anterior and posterior soft tissue will therefore be described as myofascial links.

In the selection of a starting point for the description of the inter dependence of muscles and ligaments and fascia, it was decided to follow a functional approach. In the analysis of gait, the pelvis was used as the starting point to describe how the different muscles and ligaments are linked through the fascia. The anterior and the posterior myofascial links are described separately.

2.5.3. Posterior myofascial links of the trunk

The description of the posterior myofascial links will commence with a description of the thoraco-dorsal fascia. The thoraco-dorsal fascia (TDF) is comprised of three layers, namely the anterior-, the middle- and the posterior layer (Lee, 1996; Bogduk, 1997).

The anterior layer covers the anterior aspect of the quadratus lumborum muscle (Bogduk, 1997), which in turn attaches to the superior and the anterior bands of the iliolumbar ligament (Luk *et al*., 1986; Bogduk, 1997).

The middle layer lies posterior to the quadratus lumborum and provides origin to the aponeuroses of the transversus abdominus muscle. The posterior layer of the TDF is comprised of two laminae, namely the superficial- and the deep lamina. The superficial lamina is predominantly derived from the aponeuroses of the latissimus dorsi muscle (Lee, 1996) and receives some fibres from the external oblique muscle and the lower fibres of the trapezius muscle (Vleeming, 1995). The superficial lamina blends with the fascia of the gluteus maximus muscle.

The deep lamina of the TDF attaches to the posterior sacroiliac ligaments, the lateral raphe and blends with the middle layer of the TDF. Some of the fibres of the deep lamina blend with the deep fascia of the erector spinae muscle and the sacrotuberous ligament. These links are illustrated schematically in Figure 2.5.

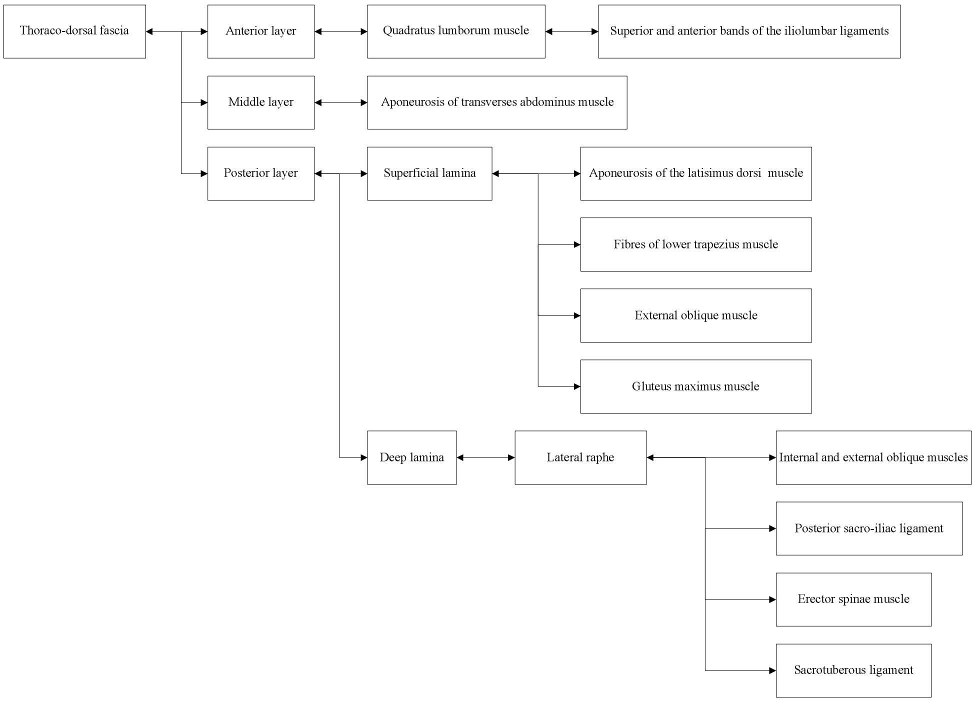

Figure 2.5: The thoraco-dorsal fascia and its links

The gluteus maximus muscle links to various muscles through facial attachments as illustrated in Figure 2.6. The fascia of the gluteus maximus muscle has attachments to the sacrotuberous ligament, the erector spinae muscle and the fascia covering the gluteus medius muscle (Lee, 1996). The gluteus maximus muscle further blends with the ipsilateral multifidus muscle through the raphe of the thoraco-dorsal fascia (Willard, 1997) and with the contra-lateral latissimus dorsi muscle through the superficial lamina of the thoraco-dorsal fascia (Vleeming, 1995).

Fibres from the multifidus muscle also blend with the sacrotuberous ligament. The majority of the fibres of the gluteus maximus muscle inserts into the iliotibial tract of the fascia lata (Farfan, 1978). Medially, fibres of this ligament attach to the deep lamina of the posterior layer of the thoraco-dorsal fascia and the aponeuroses of the erector spinae muscle (Vleeming, 1996). Connections have also been noted between the long dorsal ligament and the multifidus muscle (Willard, 1997). Laterally the fibres of the multifidus muscle blend with the superior band of the sacrotuberous ligament.

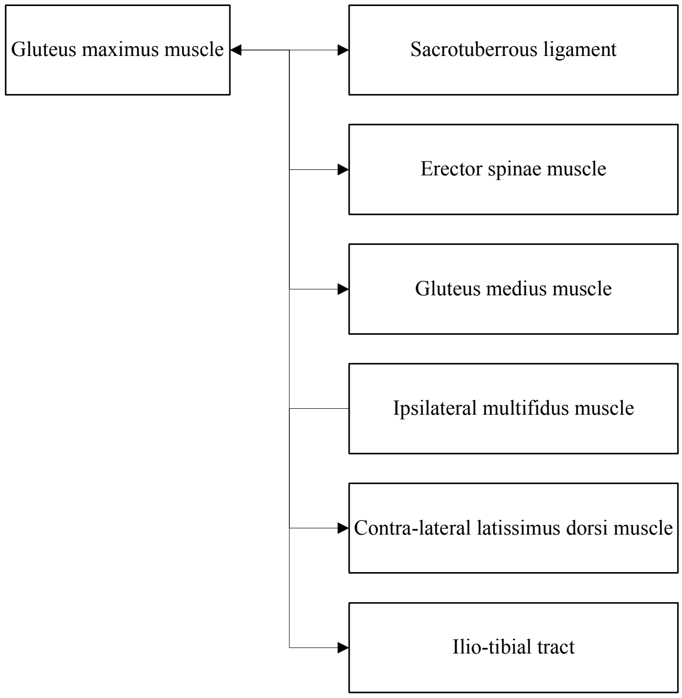

Figure 2.6: The gluteus maximus muscle and its fascia links

Myofascial links are also continuous through the sacroiliac ligaments (illustrated in Figure 2.7). The long dorsal sacroiliac ligament is covered by the fascia of the gluteus maximus muscle (Lee, 1996).

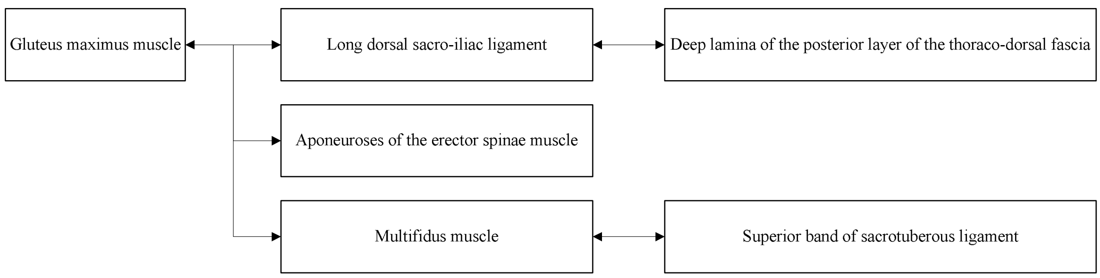

Figure 2.7: The continuity of the myofascial links through the sacroiliac ligament

The lateral band of the sacrotuberous ligament spans the piriformis muscle (Lee, 1996). In a certain percentage of humans, the sacrotuberous ligament receives some fibres from the biceps femoris muscle (Vleeming, 1996). The fibres of the biceps femoris muscle can bridge the ischial tuberosity completely to attach directly to the sacrotuberous ligament. These links are illustrated in Figure 2.8.

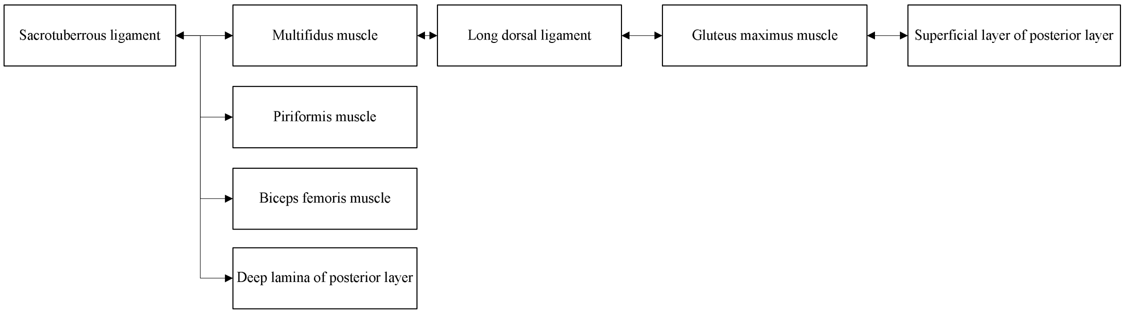

Figure 2.8: The myofascial links connecting to the sacrotuberous ligament

2.5.4. Anterior myofascial links of the trunk

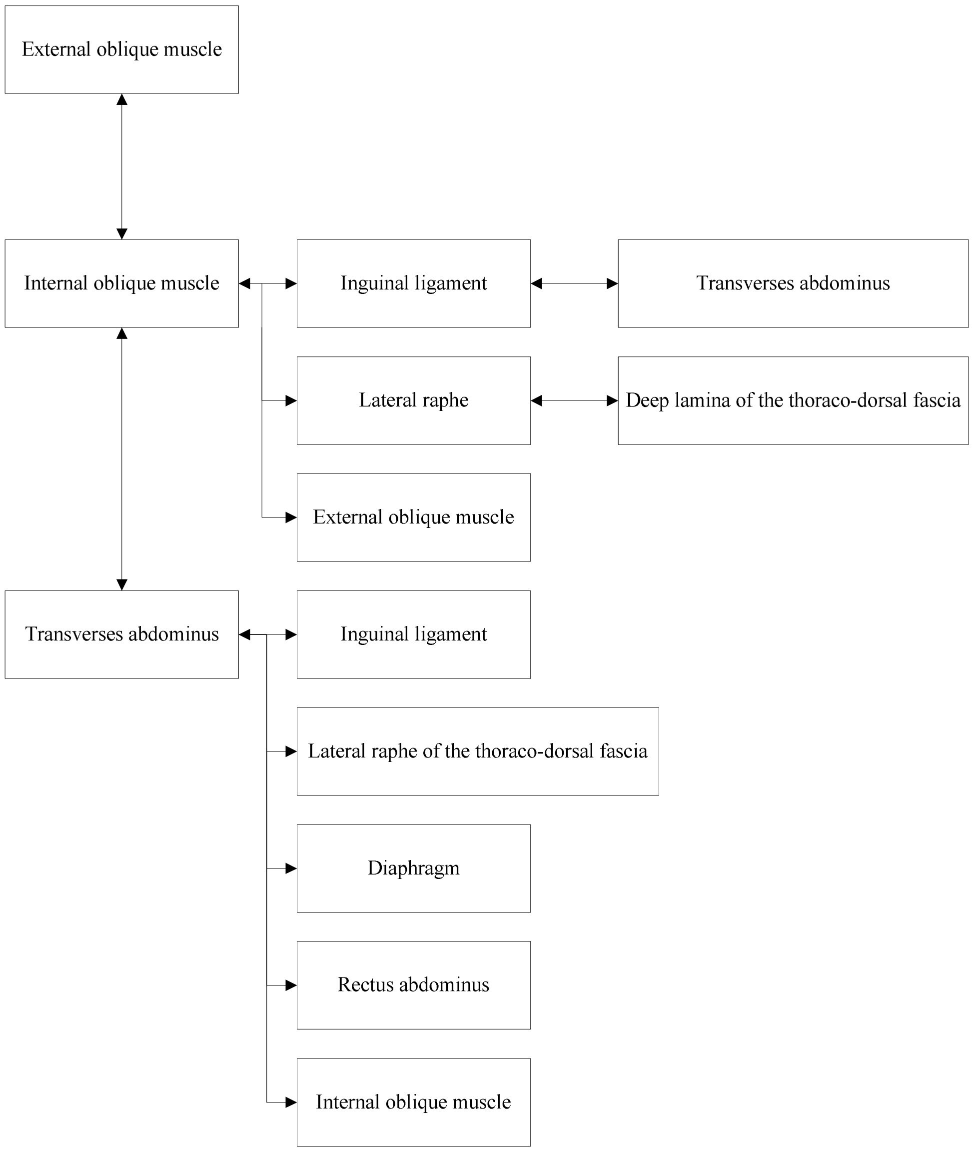

Figure 2.9: An illustration of some of the anterior myofascial links

The description of the anterior myofascial links will commence with a description of the myofascial links between the abdominal (core) muscles. Anteriorly, the external oblique muscle (the most superficial of the abdominal muscles) inserts into a complex anterior aponeuroses (Lee, 1996). The internal oblique muscle lies between the external oblique and the transversus abdominus muscles. It arises from a part of the inguinal ligament and the lateral raphe of the thoraco-dorsal fascia. The anterior fibres arising from the inguinal ligament blend with the aponeuroses of transversus abdominus (Lockhart *et al*., 1974). The transversus abdominus muscle is the deepest abdominal muscle and arises from part of the inguinal ligament, the lateral raphe of the thoraco-dorsal fascia and the internal aspect of the lower six costal cartilages inter-digitating with the costal fibres of the diaphragm. The muscle's upper and middle fibres blend with the fascial envelope of the rectus abdominus muscle. Inferiorly the muscle blends with the insertion of the internal oblique muscle (Lockhart *et al*., 1974).

There is a strong myofascial connection between the trunk and the lower limb. The thoraco-dorsal and the abdominal fascia blend with the fascia of the leg. The transversalis fascia is continuous with the iliac fossa, psoas major and psoas minor muscles. The iliacus muscle fibres, arising from the iliac fossa, converge to merge with the lateral aspect of the tendon of the psoas major muscle. The ilio-pectineal arch is a condensation of the psoas and iliac fasciae. This fascia is laterally continuous with the transversalis fascia (Lockhart *et al*., 1974). From the iliac crest, the fascia descends over the gluteus medius muscle before splitting to envelop the gluteus maximus muscle (Lee, 1996).

The fascia of psoas muscle blends anteriorly into the anterior longitudinal ligament. The anterior longitudinal ligament is continuous with the pre-vertebral fascia which is the deepest anterior fascia layer and encloses the vertebral column and its muscles (longus colli, longus capitis, rectus capitis anterior and rectus capitis lateralis) (Romanes, 1981).

The pre-vertebral fascia is attached to the anterior scalene muscle, the scalenus medius muscle and the levator scapula and the splenius capitis (Romanes, 1981; Clemente, 1996).

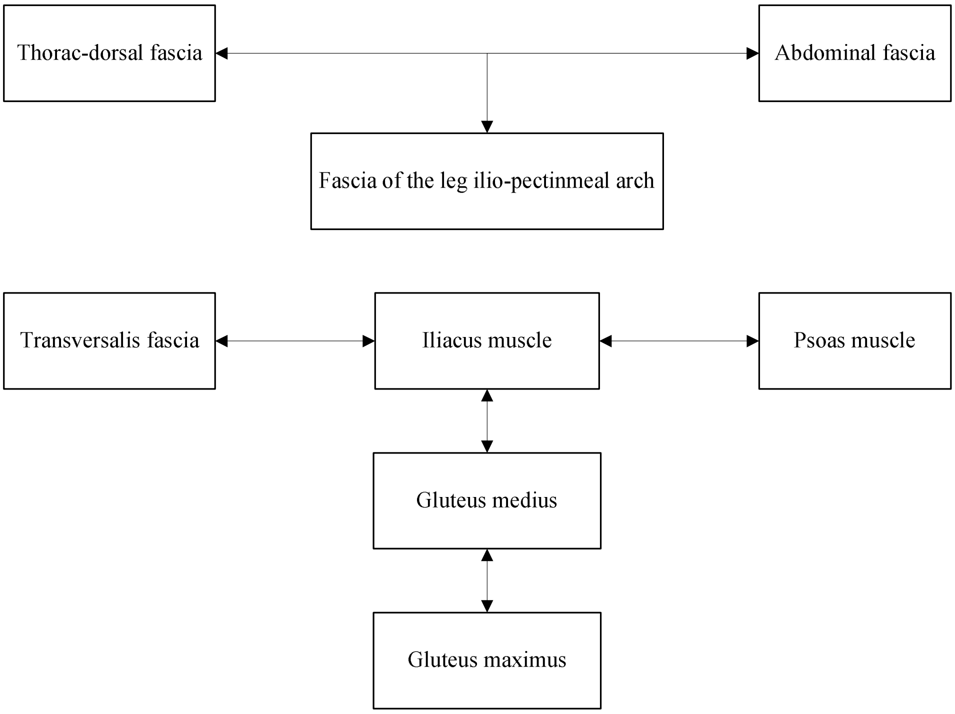

Figure 2.10: Examples of anterior and posterior trunk fascia links to one another

The scalenus anterior muscle attaches to the axillary sheath (McMinn, 1995), the brachial fascia on the flexor side (Frick *et al*., 1991), the latissimus dorsi (Frick *et al.*, 1991) and the clavi-pectoral fascia (Lockhart *et al.*, 1974). The brachial fascia is attached to the deltoid fascia on the extensor side (Frick *et al*., 1991) and to the ante-brachial fascia. The clavi-pectoral fascia is attached to the subclavius muscle which links the pectoralis major to the serratus anterior muscle and the pectoralis minor muscle (Lockhart *et al*., 1974). The pre-tracheal fascia which envelops the sterno-hyoid, the sterno-thyroid, the omo-hyoid and the thyro-hyoid muscles has a posterior link to the pre-vertebral fascia via the anterior scalene muscle. The pre-tracheal fascia also has an anterior-lateral link to the investing (most superficial) fascia via the sternocleidomastoid muscle (Romanes, 1981; Clemente, 1996). The investing fascia encloses the sternocleidomastoid and the upper trapezius muscles. The deepest layer of the investing fascia passes behind the clavicle and is attached to the sheath of the subclavius muscle (Romanes, 1981). This layer connects with the pre-vertebral fascia via the pectoral fascia.

2.5.5. Fascia of the leg

It has already been shown that there is a strong myofascial connection between the trunk and the lower leg. The tendinous fibres of the anterior-medial half of the tensor fascia lata muscle extend down the thigh and curve anteriorly at the level of the patella to interweave with the lateral patellar retinaculum and the deep fascia of the leg superficially to the patellar ligament (Travell & Simons, 1999). The fascia is continuous in the thigh with two intermuscular septa which attach to the linea aspera, namely the lateral intermuscular septum, which separates the extensors from the flexors, and the medial intermuscular septum, which separates the hamstrings from the adductors (Romanes, 1981). The medial intermuscular septum is strengthened by the fascia from the adductor magnus muscle (Romanes, 1981). Fascia of the adductor magnus muscle is also attached to the medial tibial collateral ligament (Romanes, 1981; Clemente, 1996) and to the medial head of the gastrocnemius muscle (Clemente, 1996).

There is a dense fascia network in the popliteal fossa. The tibial collateral ligament is attached to the fascia of the semimembranosus (Romanes, 1981; Clemente, 1996), and the semimembranosus fascia is attached to the oblique popliteal ligament (Clemente, 1996) and to the popliteal aponeuroses (Clemente, 1996). The oblique popliteal ligament is attached to the arcuate ligament, which is attached to the fibular collateral ligament (Clemente, 1996) and to the popliteal aponeuroses (Crafts, 1981). The popliteal aponeurosis inserts into the soleus line (Romanes, 1981) and the deep fascia of the leg is strengthened on the medial side by the insertion of the tendons of sartorius, gracilis and semitendinosus (pes anserine). The crural fascia forms the anterior, the posterior and the transverse intermuscular septum (Lockhart *et al.*, 1974). The anterior intermuscular septum separates the anterior (tibialis anterior, extensor hallucis longus, extensor digitorum and peroneus tertius) and the lateral (peroneus longus and peroneus brevis) compartments. The transverse intermuscular or interosseous membrane separates the anterior and the lateral compartments from the deep posterior (popliteus, flexor digitorum longus, tibialis posterior and flexor hallucis longus) compartment. The posterior intermuscular septum separates the superficial (gastrocnemius, soleus and plantaris) and the deep posterior compartments. Distal to the flexor retinaculum the crural fascia becomes the plantar aponeuroses.

2.5.6. Conclusion

In this chapter the utilisation of case study research as a methodology for exploratory research has been reviewed in a fair amount of detail. This has been done in the light of the fact that research in general in the medical sciences is normally based on quantitative methodologies as a result of the fact that the theoretical models in general are well developed. In these situations it is common to find research designs based on classical research designs with control groups; and double blind procedures aimed at the elimination of any form of bias during the experimentation. The lack of success with conservative treatment and by implication, a lack of a reliable theoretical model that enables the prediction of the results of interventions thus directs the research to a qualitative approach.

From the literature research it is evident that fascia plays a major role in the condition. It is also worthy to note that the only treatment with a degree of success is the surgical release of the fascia. The fact that the nature of this solution is often temporary suggests that the root cause of the problem had not been addressed.

It has also been identified that a number of conditions could mimic symptoms of chronic compartment syndromes. These include stress fractures, tendonitis (for example that of flexor hallucis longus), gastrocnemius strain, periostitis, spinal stenosis, radiculopathy, entrapments of arteries and nerves, claudication (arterio-sclerosis), and effort induced venous thrombosis (Hutchinson *et al.*, 1998). These thus provide the basis for the selection criteria for the subjects in this research project.

In the first part of the literature review on CPCS it was established that fascia exposed to physical trauma, scarring or inflammation loses its pliability. Any restriction somewhere along the myofascial chain will cause a decrease in the effective length of the myofascial chain. Such a restriction in length will induce stresses in the web during activities which require extended ranges of movement such as running. These stresses will be transmitted via the inelastic myofascial web to areas such as the posterior compartment where it will induce pressure in the posterior compartment. Whilst running, the additional forces exerted on an already compromised myofascial chain, will cause micro trauma and inflammation. The fascia will then become tight, restricted and a source of tension to the rest of the body due to the continuous nature of the myofascial web that links muscle and ligaments of various parts of the body with each other. It is therefore conceivable that a restriction or tightness in any of the more proximal muscles linked to that of the posterior compartment might contribute to the stresses in the fascia which will lead to associated pressure in the compartment.

The knowledge gained during this part of the literature review provided a new perspective on the possible causal relationships which exist in the support of the symptoms of CPCS. These new perspectives were also supported by the research results with the latter case studies where interventions outside the calf area solicited positive responses. These findings enabled the development of new treatment interventions based on a firmer theoretical footing.