CHAPTER 2

LITERATURE REVIEW

This section of the review covers the anatomy and physiology of the shoulder, its role and importance in tennis and how the shoulder is affected by normal tennis biomechanics. In this epidemiological study, it is important to understand all those factors that could influence the output of the research.

2.1 THE HISTORY OF TENNIS

2.1.1 Ancient Tennis:

Tennis is one of the few games that was not thought up by the English. Tennis began at the French Court and was played in a walled court. The balls were not only hit over the net, but also against the walls (Lawn Tennis, 1973). According to mosaics, statues and learned writings, the ancient Romans and Greeks also played a form of tennis (Brace, 1984). The medieval French also slapped a ball back and forth with their hands and called this game *"jeu de paume".* King Henry VIII rose at five in the morning to play tennis in an enclosed court at Hampton Court Palace (Brace, 1984). It started out as *Real or Royal Tennis*, much favoured by the Court and therefore sometimes known as *Court Tennis* (Lawn Tennis, 1973). He had his own professional, Anthony Ansley, who had to supply the balls and the racquets and who also kept the score. The game, which King Hal played with great "gusto", is known as *real tennis*. This *real tennis* is still played by a small group of loyal people using the same curiously shaped indoor court, lopsided rackets, and balls made of compressed cloth covered by hand-stitched felt. Real tennis became a popular game for clerics in the cloisters of French monasteries. Until this day it retains its original French names ("dedans", "grille", and "tambour") (Brace, 1984). Eventually, around 1870, the game was adapted to be played mainly outdoors on grass, and this was the beginning of

Lawn Tennis (Lawn Tennis, 1973). Lawn tennis, the outdoor version of this esoteric pursuit, only became prominent in the 19th century. The man described as the inventor was Major Walter Clopton Wingfield (Tingay, 1973; Brace, 1984). Major Wingfield was a retired Army officer and a member of Gentleman-at-Arms at the court of Queen Victoria (Wind, 1979; Brace, 1984). He was resident at Rhysnant Hall and attended a house party at Nantclwyd Hall, where the game was first played in 1873 (Tingay, 1973; Brace, 1984). He published a book of rules in December 1873 and then two months later he applied for a patent on "A New and Portable Court for Playing the Ancient Game of Tennis". Major Wingfield called his game *Sphairristike.* This Greek word was soon abbreviated to "Sticky" and then eventually it was abandoned in favour of "Lawn Tennis" which was easier to pronounce and to remember (Brace, 1984). The game came in a painted box that contained poles, pegs and netting to create a court, also four tennis bats, a supply of hollow India rubber balls, a mallet and brush and a book with the rules of the game. It cost five guineas and was designed to be played on grass, ideally on frosty days when the best of shooting was over and the ground was too hard for hunting (Tingay, 1973; Wind, 1979; Brace, 1984).

There is also firm evidence that Lawn Tennis was played at Edgbaston in 1858 and then subsequently at the Manor House Hotel, Leamington, where a plaque states clearly: 'On this lawn in 1872 the first lawn tennis club in the world was founded" (Tingay, 1973; Brace, 1984). Major Harry Gem and Mr. J.B. Perera were the initiators here. Their court was rectangular, unlike the hourglass shape of Major Wingfield's court. The rules of their game was compiled by Major Harry Gem and it is therefore fairer to *link* the two Majors – Gem and Wingfield – in awarding the credit for launching Lawn Tennis (Tingay, 1973; Brace, 1984). The tennis and racket sub-committee of the Marylebourne Cricket Club (MCC) started to revise the rules of real tennis and new rules were published on the 3rd of March 1875. A significant innovation was that the serve should be delivered with one foot behind the baseline and aimed alternately into the opposite square of the court between the net and the service line. The score went up to 15 points with deuce-advantage played at 14/14 (Tingay, 1973). This was a very important step towards uniformity in tennis, but a far more momentous development occurred in 1877. The All-England Croquet Club decided to stage a tournament at its grounds at Worple Road, Wimbledon (Brace, 1984). The goal was to raise money for the repair of a pony-roller (Brace, 1984). The pony-roller is a roller that was designed to be drawn by a horse or a pony. It stands behind the stop netting on the north side of Centre Court at Wimbledon. The roller was so wide, that having been used to level the immaculate turf when the new All England Club was built in 1922, there is now no way of removing it from of the arena, for all the exits are too narrow (Tingay, 1973). A Committee consisting of Henry Jones, Julian Marshall and C.H. Heathcote was entrusted to finalize the rules of the MCC, and came up with the rules, which have held to the present day. They agreed that the court should be rectangular, 23,8 meters long and 8,2 meters wide, and that tennis scoring should be used. They laid the foundations of Lawn Tennis, as we know it today. This major event was the world's first Lawn Tennis Tournament and the birth of Wimbledon, which remains the centerpiece of the game (Lawn Tennis, 1973; Tingay, 1973; Brace, 1984). Major Wingfield was awarded the M.V.O. in 1902 and died in April 1912 in his eighties (Tingay, 1973).

An American, Mary Outerbridge, succumbed to the game in Bermuda where the British garrison played the game and constructed a court on Staten Island, New York, in 1874. In America the game was called "Court Tennis". Thus Lawn Tennis has crossed the Atlantic Ocean (Brace, 1984). In 1881, eight years after Major Walter Lopton Wingfield had advised the game of Lawn Tennis, this country set up its own governing body. This was called the United States National Lawn Tennis Association, with thirty-four clubs affiliated with it (Tingay, 1973; Wind, 1979). A few years ago a startling communiqué was released from the U.S.L.T.A.'s main office that in the future, the U.S.L.T.A. would become the U.S.T.A. (United States Tennis Association). This made sense, for their national championships were no longer played on grass, but on a synthetic clay-like surface called Har-Tru (Wind, 1979).

The tennis scoring terms ‘fifteen’ for one point, ‘thirty’ for two points and ‘forty’ for three points puzzles the minds. This scoring came about by recording the progress of rallies (called ‘rest’ in real tennis) on a clock alongside the court. Once the player had won one point his pointer moved to one quarter, the fifteenth minute division. Winning the second point would take him to the next quarter, to thirty minutes. On the third point the marker moved to the three-quarter, to forty-five minutes. It was only during the eighteenth century that the convention arose to abbreviate ‘forty-five’ to ‘forty’. Once the full cycle was completed, it marked a game. This contest was set in order to comprise so many games (Tingay, 1973).

2.1.2 South Africa’s Tennis History:

It all began in Port Elizabeth, as did many other sports in South Africa. The first cricket test in South Africa was played in Port Elizabeth, so was the first international rugby test, and so, in 1891, was the inaugural South African tennis championship tournament also played in Port Elizabeth (Eldridge, 1978). It was written in 1897 that the inaugural South African Championships were ‘the forerunner of many enjoyable and first-class matches’ (Eldridge, 1978; Van der Merwe, 1992).

South African championships can be divided into four eras:

- First era: This was the time between 1891 and the Anglo-Boer War when the Port Elizabeth Lawn Tennis Club instituted the national championships. This open tournament at Port Elizabeth extended over four days and it was the event of the year for the whole of South Africa;
- Second era: This era followed the formation of the South African Lawn Tennis Union in 1903. This tournament started to circulate between Johannesburg, Cape Town, Durban, Port Elizabeth, East London, Pretoria, Bloemfontein and Kimberley;
- Third era: This period started in 1931 when Ellis Park, Johannesburg, was made the official, permanent venue for this event; and

- Fourth era: This stage was launched in 1966 when SALTU started to promote this tournament internationally.
  (Grace, 1975; Eldridge, 1978; Van der Merwe, 1992)

Today, tennis is still going strong in South Africa with S.A.T.A (South African Tennis Association) leading the way.

2.2 ANATOMY OF THE SHOULDER

According to Marieb (1995) joints are the weakest parts of the whole skeleton. Their two basic functions are to hold the skeleton together and to provide mobility (Hay & Reid, 1999; Martini *et al*., 2001). Their specific structure enables the joints to resist crushing, tearing and various forces that could force them out of alignment (Marieb, 1995; Roetert, 2003).

Structurally, joints can be classified as:

a. Fibrous joints:

These bones are joined by fibrous tissue with no joint cavity present. There are three types of fibrous joints: sutures (found in the cranial bones in the skull), syndesmoses (for example the interosseous membrane connecting the radius and ulna along their length) and gomphoses (the articulation of a tooth) (Marieb, 1995; Martini *et al*., 2001; Roetert, 2003).

b. Cartilaginous joints:

Cartilage unites the articulating bones in cartilaginous joints. There are two types of cartilaginous joints:

- ***Synchondroses***: This is found in the epiphyseal plates connecting the diaphysis and epiphysis regions in long bones; and
- ***Symphyses:*** Found in the intervertebral joints and the pubic symphysis of the pelvis (Marieb, 1995; Hay & Reid, 1999; Martini *et al*., 2001).

c. Synovial joints:

This is where the articulating bones are separated by a fluid-containing joint cavity, which permits substantial freedom of movement. All the joints of the limbs fall into this category (Marieb, 1995; Martini *et al*.2001).

Functionally, joints can be classified as:

a. **Synarthoses:** Immovable joints, which are mainly restricted to the axial skeleton;

b. **Amphiarthoses*:*** Slightly movable joints, which are also mainly restricted to the axial skeleton ; and

c. **Diarthoses:** Freely movable joints which predominate in the limbs (Marieb, 1995; Hay & Reid, 1999).

Functionally and structurally the shoulder is a diarthoses, synovial joint (Marieb, 1995).

2.2.1 Synovial Joints:

2.2.1.1 General structure:

As mentioned earlier, synovial joints are articulating bones separated by a fluid-containing joint cavity, which allows freedom of motion (Marieb, 1995; Martini *et al*., 2001). Typically, these joints have five distinguishing features **(Figure 1):**

i. Articular cartilage:

Hyaline, which is a glassy-smooth articular cartilage, covers the opposing bone surfaces. These spongy cushions absorb compression placed on the joint, and it keeps the bone ends from getting crushed (Marieb, 1995; Martini *et al*., 2001).

ii. Joint cavity:

The joint cavity is filled with synovial fluid and is thus more of a potential space rather than a real one (Marieb, 1995; Martini *et al*., 2001).

iii. Articular capsule:

A double-layered articular capsule encloses the joint cavity. The external layer is a strong and flexible fibrous capsule that is continuous with the periostea of the articulating bones (Marieb, 1995; Martini *et al*., 2001).

iv. Synovial membrane:

This membrane is composed of loose connective tissue. It lines the fibrous capsule internally and covers all the internal joint surfaces that are not hyaline cartilage (Marieb, 1995; Martini *et al*., 2001).

v. Synovial fluid:

All free spaces within the joint capsule are filled up by a small amount of slippery synovial fluid. This fluid is largely derived by filtration from the blood that flows through the capillaries in the synovial membrane (Hay & Reid, 1999). Due to its content of hyaluronic acid secreted by the cells of the synovial membrane, synovial fluid has a viscous, egg white consistency. During joint activity the fluid warms and becomes thinner and less viscous (Marieb, 1995). Synovial fluid is also found within the articular cartilage and it provides a slippery, weight bearing film that reduces friction between the cartilages. ***Weeping lubrication*** is a mechanism that squeezes synovial fluid out and into the cartilage during movements, lubricating their free surfaces and nourishing their cells. This synovial fluid is forced from the cartilage every time a joint is compressed. As the pressure on the joint is relieved, the fluid seeps back into the articular cartilage, ready to be squeezed out the next time the joint is under pressure **(Figure 1)** (Marieb, 1995; Hay & Reid, 1999; Martini *et al*., 2001; Roetert, 2003).

Some synovial joints are reinforced and strengthened by ligaments. Most often, the ligaments are intrinsic (capsular) and are thickened parts of the fibrous capsule. In some other joints, the ligaments remain distinct and are found either outside the capsule (extra- capsular) or deep in it (intra- capsular) (Hay & Reid, 1999).

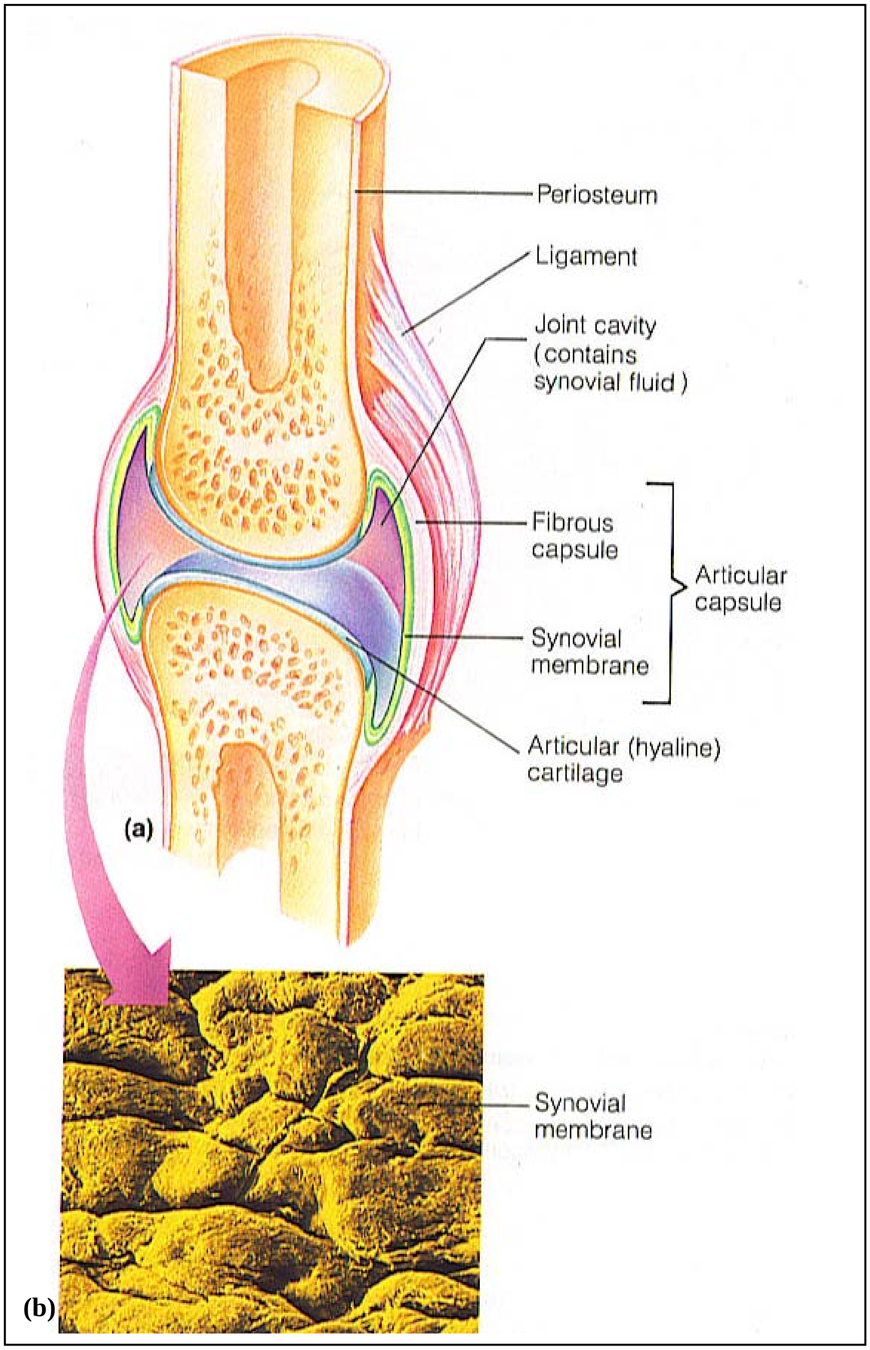


Figure 1: General structure of a synovial joint. **(a)** The articulating bone ends are covered with articular cartilage and they are enclosed within an articular capsule. The fibrous capsule, the exterior portion of the articular capsule, is continuous with the periostea of the bones. Internally, the fibrous capsule is lined with very smooth synovial membrane that secretes the synovial fluid. Ligaments typically

reinforce these joints. **(b)** Scanning electron micrograph of the synovial membrane of a knee joint (Marieb, 1995).

2.2.1.2 Bursa and tendon sheath:

Bursae and tendons are not strictly part of synovial membranes, but are often found closely associated with them **(Figure 2)** (Marieb, 1995).

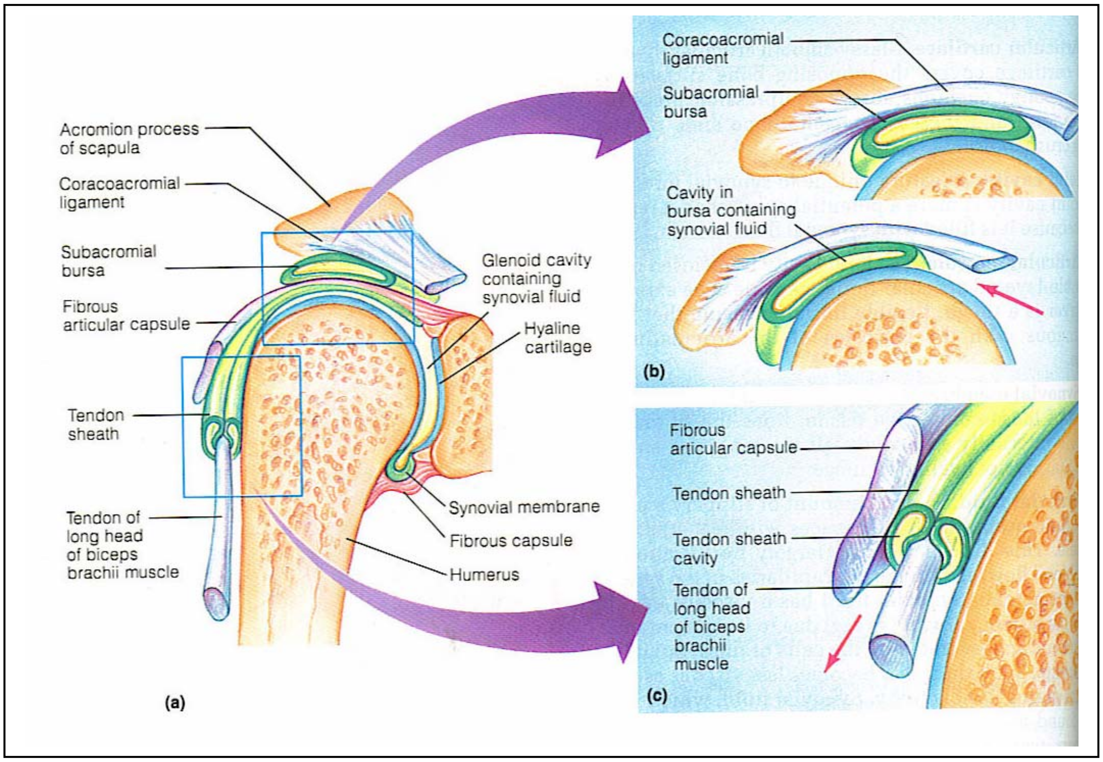


Figure 2: Friction-reduction structures: Bursae and tendon sheaths. **(a).** Frontal section through the right shoulder joint indicating the sac-like bursae and the tendon sheath around a muscle tendon. **(b)** An enlargement of part (a), indicating the manner in which a bursae eliminates friction where a tendon is liable to rub against a bone. The synovial fluid inside the bursae acts as a lubricant that allows the walls to slide easily across each other. **(c)** An enlarged three-dimensional view of the tendon sheath wrapped around the tendon of the biceps brachii muscle (Marieb, 1995).

Bursae, meaning "purse" in Latin, are flattened fibrous sacs lined with synovial membrane and containing a thin film of synovial fluid (Martini *et al*., 2001; Roetert, 2003). They are usually present in sites where ligaments, muscles, skin or muscle tendons lie over and rub against a bone (Marieb, 1995; Hay & Reid, 1999). Many people have never heard of a bursa, but most people are familiar with the word "bunion". A Bunion is an enlarged bursa at the base of the big toe that becomes swollen up due to rubbing against a tight or poorly fitting shoe (Martini *et al*, 2001).

A ***tendon sheath*** is an elongated bursa that wraps completely around a tendon where it is subjected to friction (Marieb, 1995; Hay & Reid, 1999).

2.2.1.3 Factors influencing the stability of synovial joints:

Joints are consistently stretching and compressing, therefore they must be stabilized in order not to dislocate (Marieb, 1995; Roetert, 2003). The stability of a synovial joint depends mainly on the following three factors:

i. Articular surface:

The articular surface determines the movements that are possible at a specific joint, but they play a minimal role in joint stability. Many joints have shallow sockets that contribute little to joint stability. Other surfaces, for example the hip joint, are large and fit snugly together, therefore improving stability (Marieb, 1995; Martini *et al*., 2001; Montalvan *et al*., 2002).

ii. Ligaments:

Ligaments of synovial joints unite the bones, direct movement and prevent excessive and undesirable movement. The more ligaments around the joint, the stronger it is (Martini *et al*., 2001). Although, when the other stabilizing factors are inadequate, tension is placed on the ligaments, causing them to stretch. A stretched ligament stays stretched, and can only be stretched by 6% of its original length before in snaps (Marieb, 1995). Where ligaments are the major means of bracing a joint, the joint is not very stable (Marieb, 1995; Hay & Reid, 1999).

iii. Muscle tone:

Muscle tone can be defined as low levels of contractile activity in relaxed muscles, and helps to keep the muscles healthy and ready to react to stimulation (Marieb, 1995; Martini *et al*., 2001; Roetert, 2003). In most joints, the muscle tendons that cross the joint are the most important stabilizing factor and these tendons are kept taut at all times by *the tone of their muscles*. This muscle tone is extremely important in reinforcing the shoulder and knee joints as well as the arches of the foot (Marieb, 1995, Hay & Reid, 1999; Martini *et al*., 2001).

2.2.2 STRUCTURE OF THE SHOULDER (glenohumeral) JOINT:

2.2.2.1 General structure:

The upper extremity is similar to the lower extremity in that they are both connected to the trunk via a bony ring, or girdle (Hamill & Knutzen, 1995). The shoulder joint is a synovial joint where the articulating bones are separated by a fluid-containing joint cavity. The glenohumeral joint is the most freely moving diarthoses in the body (Marieb, 1995). Two clavicles and two scapulae form the shoulder girdle. The upper extremity connects to the trunk via the sternum, and the shoulder forms an incomplete ring due the fact that the scapulae do not make contact with each other in the back. This allows independent motion of the right and left arms. In contrast, the lower extremity connects to the trunk via the sacrum. This forms a complete ring with the pelvic girdle, since both sides of the pelvis are connected to each other, both anteriorly and posteriorly (Hamill & Knutzen, 1995, Hay & Reid, 1999; Roetert, 2003). The shoulder girdle has additional skeletal attachments on the lateral sides of the body, with the head of the humerus of the arm. It has to support the limbs, which increases its insecurity further (Hay & Reid, 1999).

Where the function of the lower extremity involves mainly weight bearing, ambulation, posture and gross motor activities, the upper extremity participates in activities requiring skills in manipulation, dexterity, striking, catching, and fine motor abilities. Therefore, the shoulder is the most mobile extremity (Hamill & Knutzen, 1995). The shoulder is a ball-and-socket joint, formed by the small, shallow, pear-shaped glenoid cavity of the scapula and the head of the humerus **(Figure 3)** (Marieb, 1995). In ball-and-socket joints, the hemispherical or spherical head of one bone articulates with the concave socket of another bone. These joints are multi-axial with universal movement in all axes and planes **(Figure 4)** (Marieb, 1995; Hay & Reid, 1999).

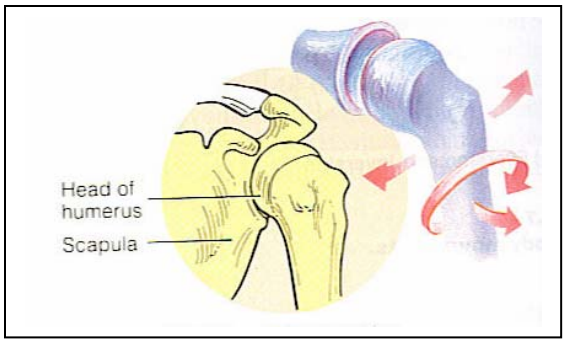


Figure 3: Ball-and-socket joint: The shoulder (Marieb, 1995).

In the shoulder, the glenoid cavity is slightly deepened by the glenoid labrum, which is a rim of fibro- cartilage, but it is only about one-third of the size of the humeral head and contributes little to joint stability. There is a thin articular capsule that encloses the joint cavity from the margin of the glenoid cavity to the anatomical neck of the humerus. It is remarkably loose, contributing to the joint's freedom of movement (Marieb, 1995).

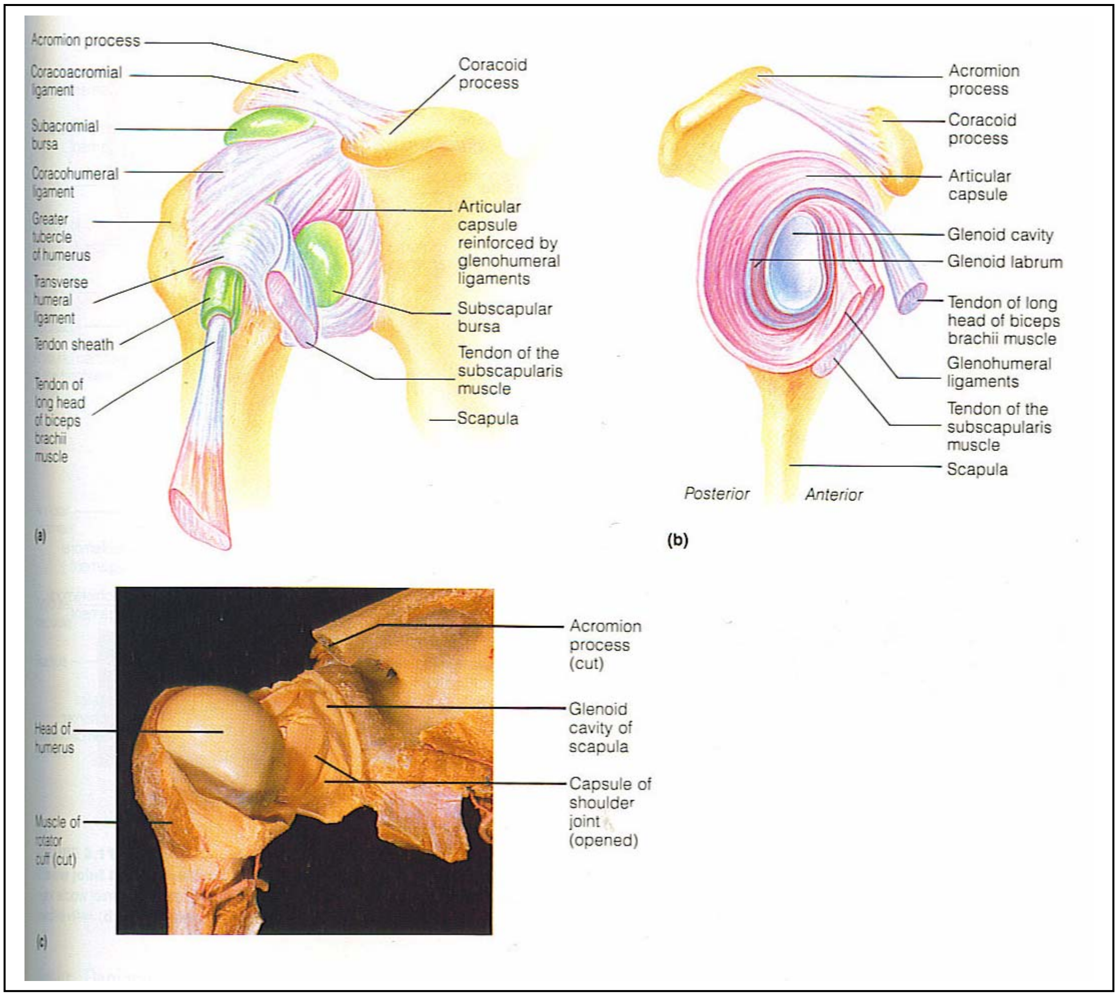


Figure 4: Shoulder joint relationships. **(a)** An anterior view of the shoulder joint (superficial aspect) illustrating some of the reinforcing ligaments, associated muscles and bursae. **(b)** The right shoulder joint, cut open and viewed from a lateral aspect where the humerus has been removed. **(c)** Anterior view of the interior of the shoulder joint: A photograph (Marieb, 1995).

a. The Scapula:

The scapula is a flat bone that is roughly triangular in shape with a *medial, lateral* and *superior* border (Hey & Reid, 1999). It consists of three angles that are *superior, lateral* and *inferior.* The *costal surface* that is closer to the surface of the scapula is slightly concave in order to correspond with the shape of the rib cage (Hamill & Knutzen, 1995; Martini *et al*., 2001). The *dorsal surface* has a prominent ridge, which forms the spine of the scapula. This ridge extends laterally and ends in the *acromion process*, the point at which the clavicle articulates. The *glenoid fossa* is a shallow concave articular surface inferior to the acromion and it articulates with the head of the humerus. The *coracoid process* projects forward under the clavicle and toward the head of the humerus all the way from the superior border medial to the glenoid fossa **(Figure 5)** (Hay & Reid, 1999).

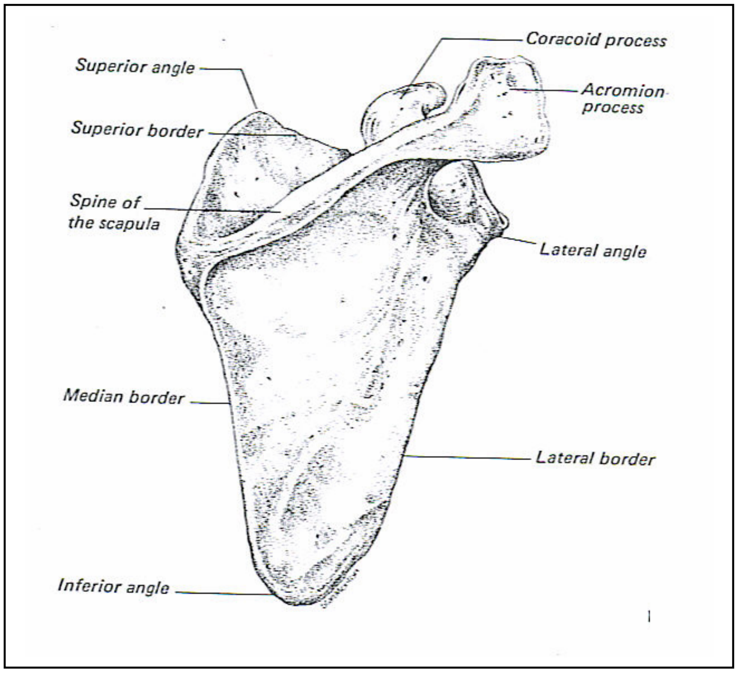


Figure 5: Posterior view of the right scapula (Hay & Reid, 1999).

b. The Clavicle:

The clavicle has the appearance of an elongated “S” and it articulates with the acromion process of the scapula on the lateral side and on the medial side with the sternum. The medial half of the bone is anteriorly convex and the lateral side is concave (Hay & Reid, 1999; Roetert, 2003).

c. Joints of the Shoulder Girdle:

The shoulder girdle consists of ***two joints***, which on each lateral side has a glenoid fossa for articulation with the head of the humerus:

i) ***The Sternoclavicular Joint:***

This joint is a synovial joint between the medial end of the clavicle and the superior lateral corner of the manubrium of the sternum and the cartilage of the first rib. A *fibrous capsule* covers the articulation and provides strength to the joint by an:

- anterior and posterior sternoclavicular ligament;
- interclavicular ligament; and a
- costoclavicular ligament (Marieb, 1995; Hay & Reid, 1999).

The sternoclavicular joint is a very strong joint and dislocation is uncommon. If the acromion of the scapula is struck or when a force is transmitted from an outstretched arm when the hand strikes the ground on falling, it is likely that the clavicle may break, but the joint will rarely dislocate (Hay & Reid, 1999; Martini *et al*., 2001).

ii) ***The Acromioclavicular Joint:***

The acromioclavicular joint, which is also an arthrodial joint, forms the union between the lateral end of the clavicle and the acromion process of the scapula. The superior and the inferior acromioclavicular ligaments aids in supporting the joint (Marieb, 1995; Hay & Reid, 1999). The coracoclavicular ligament, which is not part of the joint, helps to maintain the integrity of the joint. Dislocation of this joint is common in contact sports when the athlete falls on his shoulder and this condition is often incorrectly referred to as a "shoulder separation" (Hamill & Knutzen, 1995; Hay & Reid, 1999; Martini *et al*., 2001).

2.2.2.2 Ligaments:

There are three ligaments reinforcing the shoulder joint, located primarily on its anterior aspect:

i) Coracohumeral ligament*:*

This ligament extends from the coracoid process of the scapula to the greater tubercle of the humerus. It provides the only strong thickening of the capsule and it helps to support the weight coming from the upper limb (Marieb, 1995; Martini *et al*., 2001).

ii) Glenohumeral ligament:

There are three glenohumeral ligaments, which strengthen the front of the capsule. They are very weak and in some cases may even be absent (Marieb, 1995).

iii) Transverse humeral ligament:

This ligament spans the gap between the humeral tubercles (Marieb, 1995; Martini *et al*., 2001).

2.2.2.3 Tendons:

The muscle tendons that cross the shoulder joint are far more important in stabilizing the shoulder than the ligaments (Marieb, 1995, Hay & Reid, 1999; Martini *et al*., 2001). The most important stabilizer is the *tendon of the long head of the biceps brachii muscle* **(Figure 4a)** (Marieb, 1995). This tendon stretches from the superior margin of the glenoid labrum, through the joint cavity, and then exits the cavity and runs within the intertubercular groove of the humerus. This way it secures the humerus tightly against the glenoid cavity (Martini *et al*., 2001).

Four other tendons, together with their associated muscles, collectively called the *rotator cuff*, encircle the shoulder joint and blend with the articular capsule (Yokochi *et al*., 1989). The rotator cuff consists of the subscapularis, supraspinatus, infraspinatus and teres minor muscles (**Figure 12**) (Marieb, 1995). Because of the arrangement of its muscles, the rotator cuff can be severely stretched when the arm is vigorously circumducted. The humerus usually tends to dislocate downward, since the shoulders' reinforcements are the weakest inferiorly (Marieb, 1995; Martini *et al*., 2001).

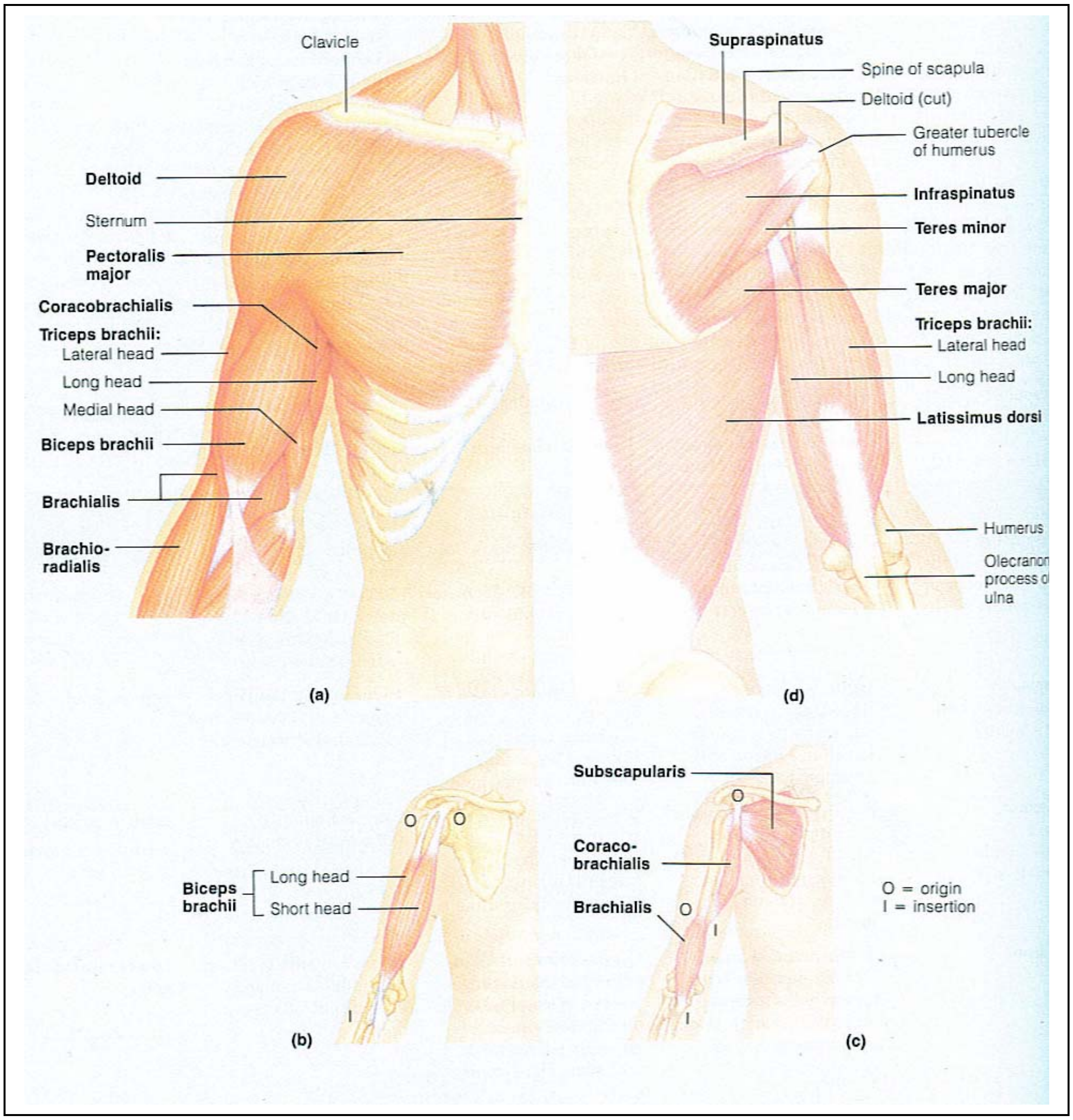


Figure 6: Muscles crossing the shoulder and elbow joints, causing movement of the arm and the forearm. **(a)** Anterior view of the superficial muscles of the anterior thorax, shoulder and arm. **(b)** The biceps brachii muscle of the anterior arm. **(c)** The brachialis muscle arising from the humerus, and the coracobrachialis and subscapularis muscles arising from the scapula. **(d)** The

extent of the triceps brachii muscle of the posterior arm, in relation to the deep scapular muscles; the deltoid muscle of the shoulder removed (Marieb, 1995).

2.3 MUSCLES AND MOVEMENTS OF THE SHOULDER GIRDLE

2.3.1 Movements of the Shoulder Girdle:

All the movements of the scapula depend on the combined motion capabilities of both the sternoclavicular and the acromioclavicular joints. The *sternoclavicular joint* permits movement in almost all directions, including circumduction. The *acromioclavicular joint* permits the gliding motion of the articular end of the clavicle on the acromion, and also some rotation of the scapula both forward and backward on the clavicle (Hay & Reid, 1999). The movements of the scapula in combination with the clavicle are as follows:

i. Adduction and abduction:

Adduction of the scapula occurs when the medial border of the scapula moves *toward* the spine and *abduction* of the scapula when the medial border moves *away* form the spine. Adduction can be seen when sticking out the chest and pulling back the shoulders (Yokochi *et al*., 1989; Hay & Reid, 1999).

ii. Elevation and depression:

Elevation is the upward movement of the scapula with no rotation, as in raising the shoulders. The downward movement of the scapula is called *depression*. Elevation and depression can be felt by placing the hand on the scapula and the clavicle either separately or simultaneously while first lifting the shoulders and then pushing them down again (Yokochi *et al*., 1989; Hay & Reid, 1999).

iii. Rotation:

The axis of rotation can be either at the sternoclavicular or the acromioclavicular joint. *Upward rotation* is the outward and upward movement of the inferior angle of the scapula. *Downward rotation* is the inward and downward movement of the inferior angle of the scapula (Hay & Reid, 1999).

2.3.2 Movements of the Shoulder Joint:

The movements of the glenohumeral joint should not be confused with those movements of the shoulder girdle, although they usually occur together and should be considered together. Extension, flexion, a slight degree of hyperextension, abduction, adduction, circumduction, medial rotation and lateral rotation may all occur at the shoulder joint, but their range of motion is limited if there is no shoulder girdle involvement (Hay & Reid, 1999). During all flexion and abduction motions of the glenohumeral joint there are simultaneous scapulothoracic (shoulder girdle) movement. The scapula remains fixed through the first 30º to 60º, but there may be motion at the joint until a stable position is obtained, or the scapula may move on the chest wall. After 30º of abduction or 60º of forward flexion, there is a constant relationship between the humeral and the scapula movement with two degrees of humeral movement for every one degree of scapular rotation **(Figure 7)** (Yokochi *et al*., 1989; Hay & Reid, 1999).

Taken from the anatomical position, the full range of movement in flexion of the arm above the head can only be accomplished if medial rotation of the humerus occurs, whereas full abduction is possible from this position (Yokochi *et al*., 1989). If abduction is attempted with the palm of the hand facing the thigh, the range of motion is limited to approximately 90º. Lateral rotation will permit further abduction from this point (Hay & Reid, 1999).

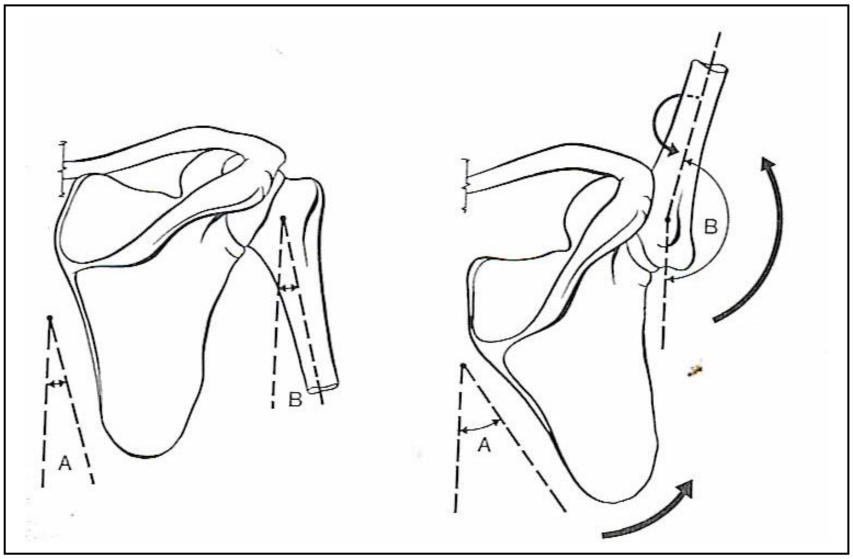


Figure 7: A posterior view of the scapula and the humerus during abduction of the humerus. **(A)** scapulothoracic angle, **(B)** glenohumeral angle (Hay & Reid, 1999).

2.3.3 Scapulohumeral Rhythm:

During the first 30º of abduction and the first 60º of forward flexion, the scapula seeks stability on the thorax (Poppen & Walker, 1976). On the other hand, research done by Freedman & Munro (1966) showed total scapular upward rotation of 65º with total glenohumeral abduction of 103º by using radiographic data for five positions of abduction. Their conclusion was that for every two degrees of scapular motion there are three degrees of glenohumeral movement. According to Doody *et al*. (1970) this discrepancy between the data of Freedman & Munro (1966) and those of others may be due to the fact that motion was allowed to occur in a coronal versus a scapular plane, the latter being 30º - 45º anterior to the true coronal plane. Under loaded conditions the scapular contribution gets called upon earlier in the range. It is generally agreed that the ratio of two degrees of glenohumeral motion to every three degrees of scapular movement is accurate, particularly when the total range of motion is considered (MacConaill & Basmajian, 1969; Doody *et al*., 1970; Frankel & Nordin, 1980; Michiels & Grevenstein, 1995; Soderberg, 1997; Roetert, 2003). Overall, we would concede that the range of scapular motion does not likely exceed 60º and the glenohumeral joint does not exceed 120º (Soderberg, 1997). The primary motion that occurs at the sternoclavicular during arm raising is *elevation.* Poppen & Walker (1976) reported an approximate 35º - 45º elevation of the clavicle by evaluating acromial elevation. Most of this motion occurred during the first 90º of elevation, meaning a 4º - 5º of elevation during each 10º of the first half of the full range of arm elevation. Together with this sternoclavicular elevation, motion also occurs at the acromioclavicular joint. The coracoclavicular ligament pulling action on the inferior aspect of the clavicle causes the clavicle to rotate around its own axis (Soderberg, 1997; Martini *et al*., 2001; Roetert, 2003). This posterior rotation of the clavicle creates movement of the lateral clavicle on the acromion. During the first 30º and from 135º to the maximum level of elevation, rotation of the acromioclavicular joint occurs around the longitudinal axis of the clavicle. The summation of these motions at the sternoclavicular, glenohumeral, scapulothoracic and the acromioclavicular joint creates the ability of humans to raise their arms above their heads (Soderberg, 1997).

2.3.4. Muscles of the Shoulder:

There are four important pairs of muscles on the **posterior aspect** of the trunk that act on the shoulder girdle:

a. The Trapezius:

The trapezius is a large triangular-shaped muscle that can be divided into four parts each with it own innervations (**Figure 8**).

i) The upper part is a thin sheet like muscle that is attached from the base of the skull to the neck of the clavicle. Its prime function is elevation of the scapula and it is therefore very active during weight bearing of the upper limb such as carrying a suitcase.

ii) The second part is immediately below the first part and is attached to the acromion. This part is involved in the elevation and upward rotation and assists in adduction.

iii) Next below is the third part and the prime mover for adduction of the scapula.

iv) The fourth part is involved with the upward rotation and depression and assists in adduction (Hay & Reid, 1999; Martini *et al*., 2001).

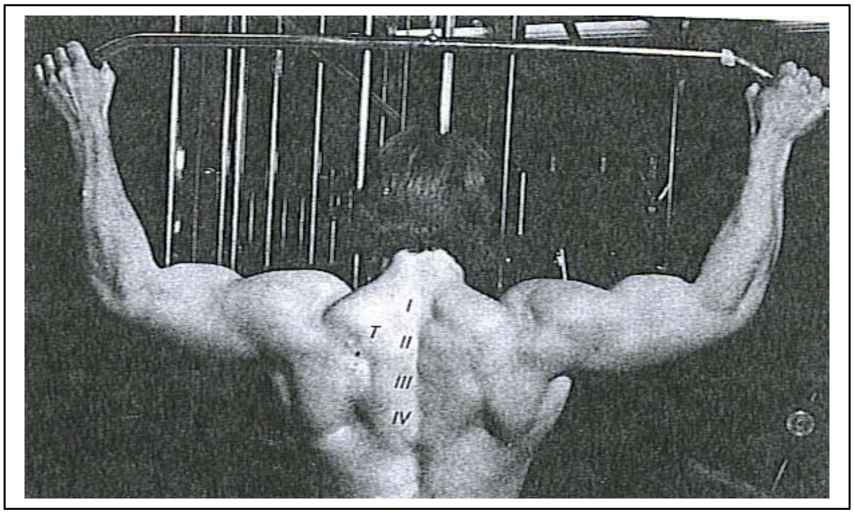


Figure 8: The trapezius (T) in action indicating the four heads (Hay & Reid, 1999).

The primary role of the trapezius is to support the upper limb upon the axial skeleton (Soderberg, 1997). It also causes and maintains upward rotation of the scapula on the thorax (Bearn, 1961).

b. The Levator Scapula:

The levator scapula is a small muscle that is situated deep to the upper part of the trapezius. Its main function is elevation of the shoulder (Hay & Reid, 1999; Martini *et al*., 2001).

c. The Rhomboid Major and Minor:

These muscles are located below the trapezius. They are strong adductors of the scapula and they also contribute to downward rotation of the scapula (Hay & Reid, 1999; Martini *et al*., 2001).

There are two major pairs of muscles that act on the shoulder girdle on the **anterior aspect** of the trunk:

d. The Serratus Anterior:

This is a broad muscle situated on the lateral side of the chest where it originates on the upper eight or nine ribs (Hay & Reid, 1999). The serratus anterior has a serrated appearance and is easily visible on a well-muscled person. This muscle is inserted into the medial border of the scapula and it abducts the scapula while holding it in close proximity to the thoratic cage when it contracts during a forward-pushing action (Martini *et al*., 2001). A primary responsibility is thought to be the motion of protraction, which is the gliding of the scapula on the wall of the thorax. Also, the lower part of the serratus assists with the upward rotation of the scapula (Soderberg, 1997). A strengthened and shortened serratus anterior reduces the condition of the protruding inferior angle of the scapula and it is then referred to as a *winged scapula* (Hay & Reid, 1999; Martini *et al*., 2001).

e. The Pectoralis Major and Minor:

The pectoralis minor is a small muscle that is found deeper to the pectoralis major. It is inserted into the coracoid process and depresses the superior lateral angle of the scapula during contraction. This causes the inferior angle to protrude if it is not supported by the serratus anterior (Hay & Reid, 1999; Martini *et al*., 2001). The pectoralis major existed of superficial and deep layers until differentiation started to take place. In most animals the pectoralis minor attaches to the humerus instead of the coracoid process. However, in human beings, the coracohumeral ligament can be considered as a vestige of the former humeral attachment (Soderberg, 1997). The pectoralis major is unquestionably important for the powerful movements of the arm across the trunk (Soderberg, 1997; Roetert, 2003).

Together, the serratus anterior and the upper and lower fibers of the trapezius cause effective scapular upward rotation that can be achieved as the arm is elevated over the head (Lehmkuhl & Smith, 1996). The trapezius and the serratus anterior also act as an effective force couple in the accomplishment of scapular upward rotation (Soderberg, 1997). In order to demonstrate this, consider the axis of rotation to be in the centre of the scapula **(Figure 9)** (Soderberg, 1997). As upper, lateral fibers of the trapezius pull upward on the distal aspect of the spine of the scapula, the inferior fibers of the serratus anterior pull the inferior angle of the scapula in a lateral and anterior direction. Thus, the muscles exert torque that results from the effective use of the principle of force couples (Soderberg, 1997). According to Inman *et al*. (1944), the trapezius lost some of the fibers (due to the lack of use) that run parallel to the spine of the scapula. Also, the serratus anterior is unanticipated since this muscle has already been separated from the levator scapulae muscle by virtue of loss of the intermediate fibers that formerly connected these two muscles. The relation of these two muscles can be seen by their innervations. The levator that is supplied by cervical roots 3, 4 and a part of 5, and the C5, C6, and C7 innovations of the serratus anterior is an indication that these two muscles were once continuous with each other (Warwick & Williams, 1989; Sonnery-Cottot *et al*., 2002).

The rhomboids, teres major and latissimus dorsi form couples for purposes of lowering the arm to the side. This action is produced in pull- ups or during high velocity activities such as the tennis serve (Soderberg, 1997).

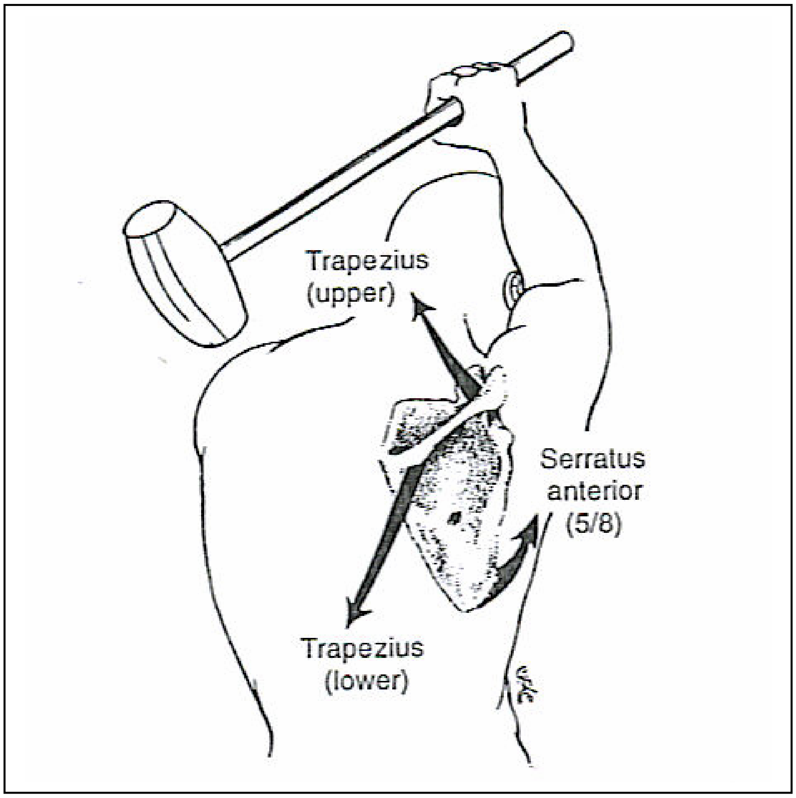


Figure 9: Representation of the action of the serratus anterior and the lower fibers of the trapezius as a force couple (Soderberg, 1997).

Table 1: Muscles acting on the shoulder girdle (Hay & Reid, 1999; Martini *et al*., 2001).

Muscle	Location	Origin	Insertion	Action
Levator scapulae	Neck (posterior)	First 4 cervical vertebrae	Medial border of scapula from the spine to the superior angle	Elevates scapula
Pectoralis minor	Chest (deep to pectoralis major)	Ribs (3rd to 5th)	Scapula (coracoid process)	Depresses scapula, pulls shoulder forward
Rhomboid major	Deep upper back	Spinous process (2nd to 5th thoracic vertebrae)	Medial border of scapula (spine to inferior angle)	Adducts and rotates scapula
Rhomboid minor	Deep upper back, superior and superficial to major	Ligamentum nuchae (lower part), 7th cervical and 1st thoracic vertebrae	Scapula spine (root)	Adducts scapula
Serratus anterior	Lateral thorax	Upper 8 or 9 ribs	Medial border of scapula	Abducts scapula
Trapezius	Upper back and neck (superficial)	Occipital protuberance, ligamentum nuchae, spine of 7th cervical and all thoracic vertebrae	Clavicle, spine of scapula, and acromion process	Adducts and rotates scapula, elevates and depresses scapula, extends neck

Table 2: Muscle acting on the shoulder joint (Hay & Reid, 1999; Martini *et al*., 2001).

Muscle	Location	Origin	Insertion	Action
Coracobrachialis	Upper arm (medial)	Scapula (coracoid process)	Humerus (middle of medial surface)	Flexion and adduction
Deltoid	Anterior, lateral and posterior upper surface of humerus	Clavicle, scapula (acromion and spine)	Deltoid tuberosity of humerus	Abducts arm, Parts: flexes, extends and rotates
Infraspinatus	Posterior surface of scapula below spine	Scapula (infraspinous fossa)	Greater tuberosity of humerus	Rotates humerus laterally
Latissimus dorsi	Lower back (superficial)	Vertebrae spines (thoracic 6th through 12th lumbar and sacral), lumbosacral fascia, crest of ileum, muscular slips from lower 3 or 4 ribs	Humerus (bicipital groove)	Adducts, extends and medially rotates humerus
Clavicular pectoralis	Chest	Clavicle (medial half)	Humerus (lateral lip of bicipital groove)	Flexes and medially rotates humerus
Sternocostal pectoralis	Chest	Sternum and costal cartilages of true ribs	Humerus (lateral lip of the bicipital groove)	Extends, adducts and medially rotates humerus
Supraspinatus	Posterior surface of scapula above spine	Scapula (supraspinous fossa)	Humerus (greater tuberosity)	Adducts humerus (assists)
Teres major	Inferior angle of scapula to humerus	Scapula (dorsal surface, inferior angle)	Humerus (bicipital groove)	Adducts, extends and medially rotates humerus
Teres minor	Immediately superior to teres major	Scapula (dorsal surface of lateral border)	Humerus (greater tuberosity)	Adducts and rotates humerus laterally

2.3.5 Muscle Groups and Surface Anatomy:

There are eleven muscles that cross the shoulder joint and contribute to motion. The muscle groups of the shoulder joint and their prime movers are the following:

i. Shoulder Flexors: *Clavicular Pectoralis and Anterior Deltoid:*

The *clavicular pectoralis* is the upper portion of the large fan-shaped muscle of the chest, the pectoralis major (Hay & Reid, 1999). There is an increase in activity that occurs in this head of the muscle during flexion with maximum activity being reached at 115º of flexion (Yokochi *et al*., 1989; Hay & Reid, 1999; Martini *et al*., 2001).

The *anterior deltoid* is a superficial muscle that may be observed and palpated with the arm abducted to 90º and is most active during resisted flexion (Martini *et al*., 2001). Inman *et al*. (1944) stated that the deltoid makes up approximately 41% of the total mass of the human abductor group. Today this value would be considered “conservative” (Soderberg, 1997). Muscle forces generate tensile loads at some given location with respect to an axis of rotation. The result is that, depending on the size of the tensile force and the perpendicular distance from which the force is applied to, will determines the resultant torque (Yokochi *et al*., 1989; Soderberg, 1997). Considering the anterior deltoid fibres while viewing the body in a frontal plane, they are superior to the axis of rotation (Figure 10a) (Soderberg, 1997). Therefore the muscle’s function for this plane is *abduction.* The same muscle viewed from a superior point will show that the muscle essentially passes anteriorly to the axis of rotation, producing *internal rotation* (Figure 10b) (Soderberg, 1997; Martini *et al*., 2001). Finally, in viewing the sagittal plane, the anterior location leads to the conclusion that a muscle contraction will cause *flexion* (Figure 10c) (Soderberg, 1997).

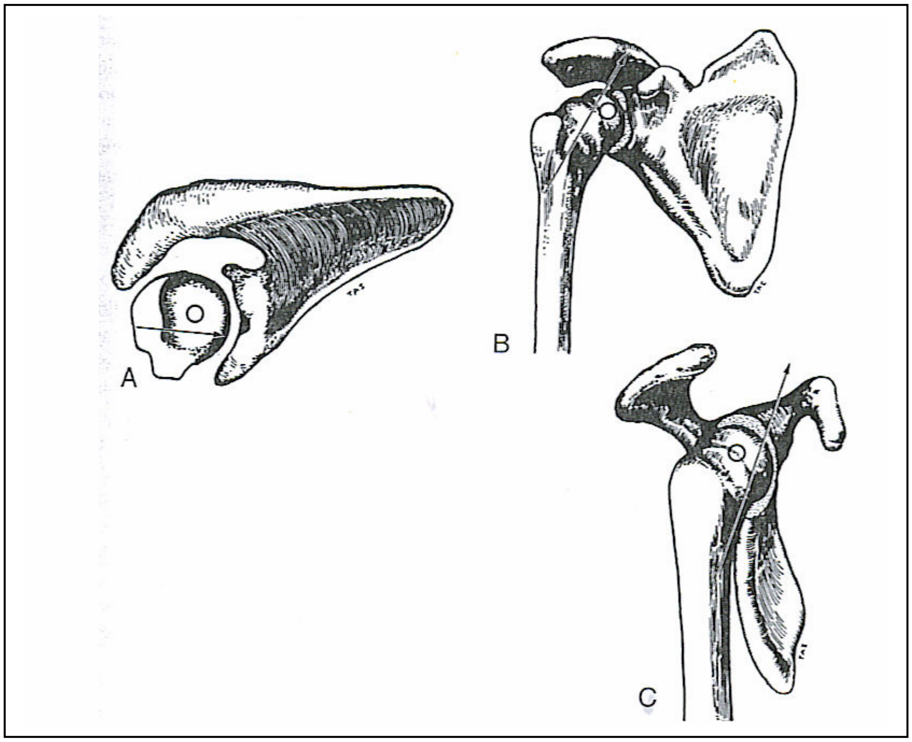


Figure 10: Triplanar diagrammatic view of the shoulder. (a) Superior, (b) Frontal, and (c) Sagittal (Soderberg, 1997).

In addition to these muscles, the coracobrachialis and the short head of the biceps also assist shoulder flexion (Hay & Reid, 1999).

ii. Shoulder Extensors*: Sternocostal Pectoralis, Latissimus Dorsi and Teres Major:*

The active contraction of the *sternocostalis pectoralis*, *latissimus dorsi* and the *Teres major* muscles makes resisted shoulder extension possible, which is found in activities such as rope climbing and pull-up exercises (Hay & Reid, 1999). The *sternocostal pectoralis* is the lower, larger part of the pectoralis muscle (Marieb, 1995). The *latissimus dorsi* is a very broad muscle on the back and it is superficial, except for a small part that is covered by the lower part of the trapezius (Hay & Reid, 1999; Martini *et al*., 2001). It is a very powerful extensor and becomes very prominent in athletes where the shoulder extensor muscles are frequently used, for example the propulsive phase of swimming (Hay & Reid, 1999). The *teres major* are active during extension against resistance but become inactive during motions without resistance.

The *posterior deltoid* and *the long head of the biceps* assist during shoulder extension (Hay & Reid, 1999).

iii. Shoulder Abductors: *Middle Deltoid and Supraspinatus:*

In the deltoid muscle, the greatest activity occurs between 90º and 180º of abduction. The *middle deltoid* is a multipennate muscle that abducts the shoulder joint and can be felt just lateral to the acromion when the arm is abducted to 90º (Hay & Reid, 1999). The *supraspinatus* is found just superior to the spine of the scapula and is deep to the deltoid and the trapezius. It is an initiator of abduction but it also assists the deltoid through 110º of abduction. Full abduction is achieved through the assistance of the anterior deltoid, clavicular pectoralis and the long head of the biceps (Hay & Reid, 1999; Martini *et al*., 2001).

iv. Shoulder Adductors*: Sternocostal Pectoralis, Latissimus Dorsi and Teres Major:*

The so-called "iron cross", a gymnastic move, is held by various vigorous contractions of these adductor muscles in order to prevent further abduction that would occur if gravity were allowed to pull the gymnast downward. The short head of the biceps and the long head of the triceps assist adduction, whereas the subscapularis and the coracobrachialis also assist when the arm is abducted above 90º (Hay & Reid, 1999).

v. Inward Rotators*: Teres Major and Subscapularis:*

Medial rotation is achieved by the action of the *subscapularis* and the *teres major* but is assisted by the anterior deltoid, clavicular and the sternocostal pectoralis, latissimus dorsi and the short head of the biceps (Hay & Reid, 1999; Martini *et al*., 2001).

vi. Lateral Rotators*: Teres Minor and Infraspinatus:*

The posterior deltoid assists the prime movers of lateral rotation, the *teres minor* and the *infraspinatus* (Martini *et al*., 2001).

vii. Horizontal Adduction*: Clavicular and Sternocostal Pectoralis, Anterior Deltoid and the Coracobrachialis:*

Horizontal adduction is performed by the contraction of the *clavicular* and the *sternocostal pectoralis, anterior deltoid* and the *coracobrachialis* muscles and is assisted by the short head of the biceps (Hay & Reid, 1999; Martini *et al*., 2001).

viii. Horizontal Abduction: *Middle and Posterior Deltoid, Infraspinatus and Teres Minor:*

The *middle* and *posterior deltoid, infraspinatus* and *teres minor* are responsible for horizontal abduction and are assisted by the latissimus dorsi and teres major muscles (Hay & Reid, 1999; Martini *et al*., 2001).

2.3.6 Prime Muscles Used in Tennis:

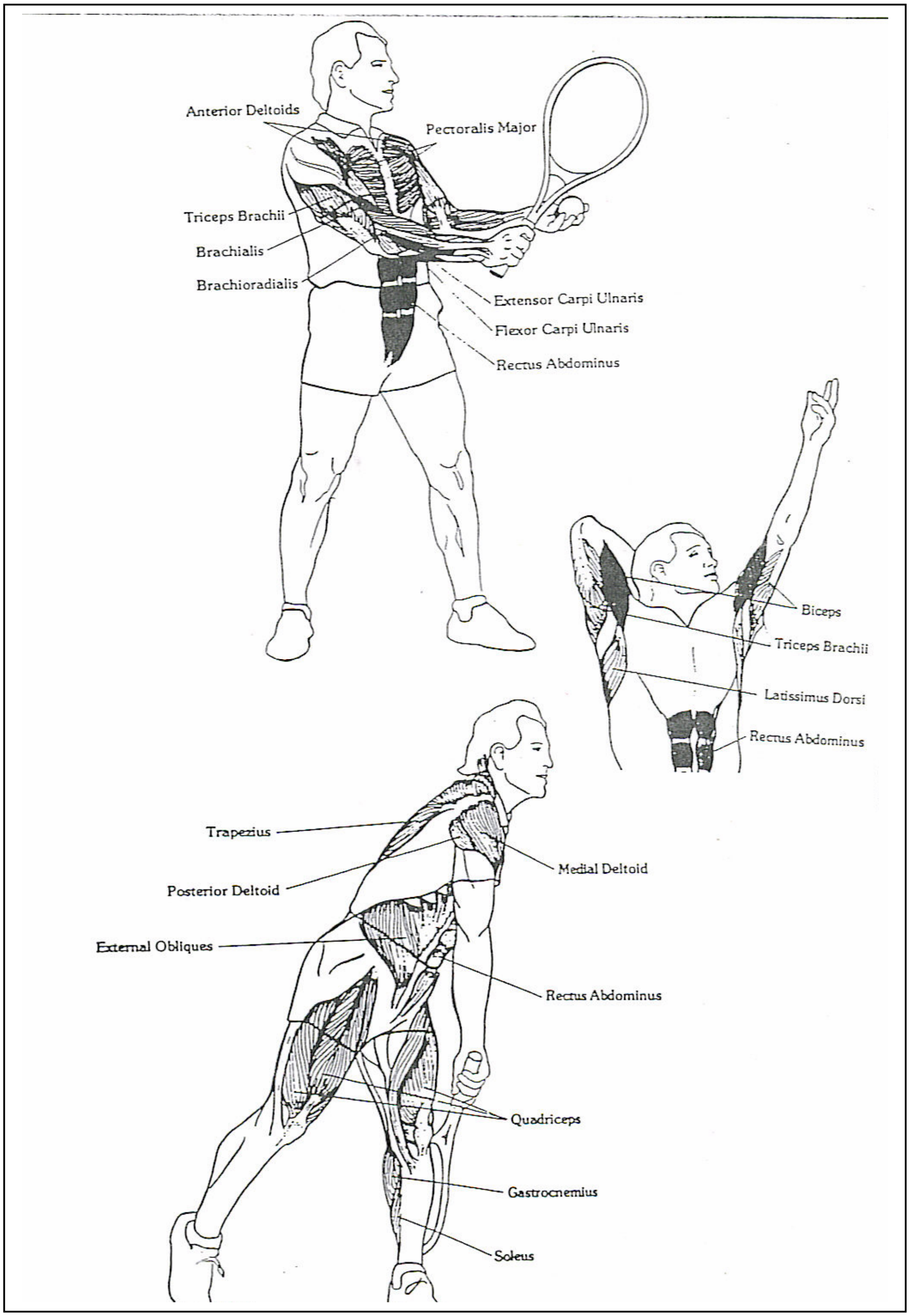


Figure 11: The primary muscles used during the tennis serve (Roetert & Ellenbecker, 1998).

Before looking at training programmes for the shoulder, it is important to know exactly what muscles are used during the different strokes in tennis. These frequently used muscles must be the target in the strength training programme, as well as those muscles that stabilize and decelerate the body. The strength-training programme must then emphasize their concentric and eccentric actions (Figure 11) (Roetert, 2003).

a. Muscles used in the forehand drive and volley:

- Anterior deltoid;
- Pectorals;
- Shoulder internal rotators;
- Elbow flexors (biceps); and
- Serratus anterior.

(Chu, 1995; Roetert & Ellenbecker, 1998)

b. Muscles used in the one-handed backhand drive and volley:

- Rhomboids and middle trapezius;
- Posterior deltoid;
- Middle deltoid;
- Shoulder external rotators;
- Triceps; and
- Serratus anterior.

(Chu, 1995; Roetert & Ellenbecker, 1998)

c. Muscles used in the two-handed backhand drive:

Non-dominant side:

- Pectorals;
- Anterior deltoid; and
- Shoulder internal rotators.

Dominant side:

- Rhomboids and middle trapezius;
- Posterior deltoids;
- Middle deltoids;
- Shoulder external rotators;
- Triceps; and
- Serratus anterior.

(Chu, 1995; Roetert & Ellenbecker, 1998)

d. Muscles used in the serve and overhead:

Arm swing:

- Pectorals;
- Shoulder internal rotators;
- Latissimus dorsi; and
- Triceps.

Arm extension:

- Triceps.

Wrist flexion:

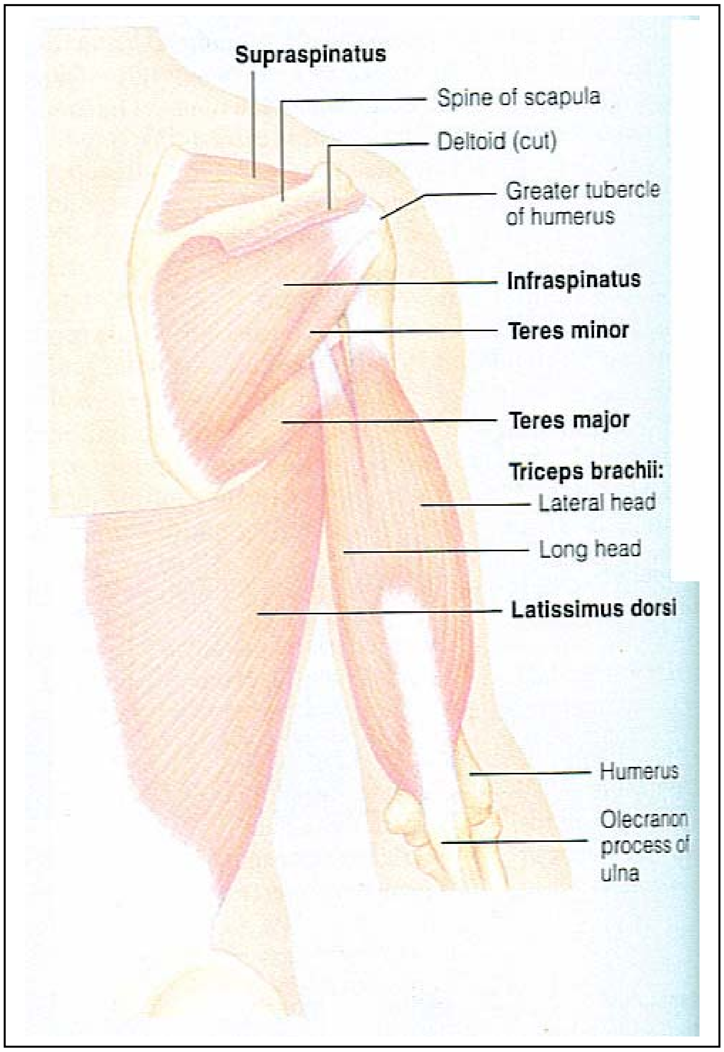
- Wrist flexors.

(Chu, 1995; Roetert & Ellenbecker, 1998)

The primary muscles that hold the humerus head in the glenoid cavity are the *rotator cuff muscles* (Figure 12). The rotator cuff consists of four muscles:

i. Supraspinatus;
ii. Infraspinatus;
iii. Teres minor; and
iv. Subscapularis.

(Roetert & Ellenbecker, 1998; Roetert, 2003)



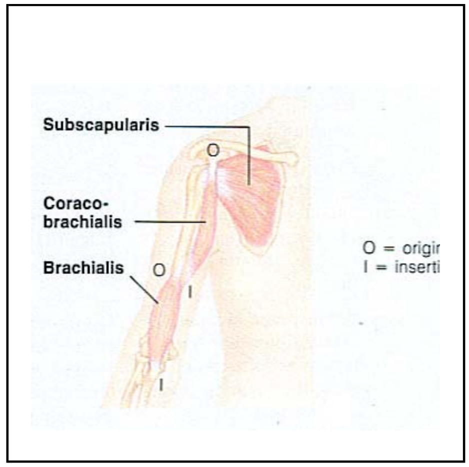


Figure 12: The Rotator cuff muscle (Marieb, 1995).

These four muscles originate back on the scapula and insert in the shoulder to form a cuff surrounding the humerus (Roetert & Ellenbecker, 1998). According to Roetert & Ellenbecker (1998) the rotator cuff is active during all the tennis strokes. It accelerates the arm forward during the strokes and the serve and then slows the arm down after ball impact and during the follow – through phase.

In spite of the relatively small individual muscle masses, the collective functions of the muscles of the rotator cuff become important in normal and pathological motions (Marieb, 1995; Hay & Reid, 1999). The rotator cuff is so labeled because of its affect upon the glenohumeral joint. Slips from all these muscles are intimately woven into the capsule of the glenohumeral joint, strengthening and reinforcing the capsule. The weakest portion of the capsule is the inferior part where the cuff muscles contribute few reinforcing fibers (Soderberg, 1997). Saha (1971) calls the rotator cuff muscles the "steerers", because they are mainly responsible for the rolling of the head of the humerus in the glenoid in different elevations, while the prime mover is raising the arm. In the research done by Saha (1971), electromyographic evidence was used to confirm the role of the subscapularis and the infraspinatus as stabilizers in the early range. He also demonstrated the electrical activity in the infraspinatus, almost solely, in the terminal phases of arm elevation.

2.4 ANALYSIS OF THE SHOULDER IN TENNIS-SPECIFIC MOVEMENTS

The following review is meant to highlight the particular muscles that accelerates, decelerates and stabilize the upper extremity during isolated movement patterns common in tennis.

2.4.1 The Serve:

According to Yoshizawa *et al.* (1987) muscular activity of the shoulder and forearm are significantly higher during the serve than during ground strokes.

The serve can be divided into four stages:

i. **"Windup":**

This phase is characterized by the initiation of the serving stance to the ball toss by the contra lateral arm. The muscular activity in both the shoulder and forearm are very low in this phase (Yoshizawa *et al*., 1987; Ellenbecker, 1995; Roetert, 2003).

ii. “Cocking phase”:

This phase begins after the ball toss and terminates at the point of maximal external rotation of the glenohumeral joint of the racquet arm (Yoshizawa *et al*., 1987; Morris *et al*., 1989; Ellenbecker, 1995).

High muscular activity has been reported in the dominant arm during the cocking phase in the following muscles:

- Serratus anterior (70%);
- Supraspinatus (53%);
- Infraspinatus (41%);
- Biceps brachii (39%); and
- Subscapularis (25%).

(Yoshizawa *et al*., 1987; Ellenbecker, 1995)

High muscular activity has been reported in the following areas during the forceful internal rotation of the glenohumeral joint:

- Pectoralis major;
- Latissimus dorsi;
- Subscapularis; and
- Serratus anterior.

(Morris *et al*., 1989; Ellenbecker, 1995)

High muscular activity has been reported in the following areas during acceleration:

- Pectoralis major;
- Deltoid;
- Trapezuis; and

- Triceps.

(Yoshizawa *et al*., 1987; Morris *et al*., 1989; Ellenbecker, 1995)

iii. Ball Contact:

Studies done by Miyashita *et al*. (1980), Yoshizawa *et al*. (1987), Rhu *et al*. (1988) and Roetert (2003) show a relative silence of electrical activity in the acceleration muscles during impact with a peak activity occurring just prior to impact. Only the *infraspinatus* remains active during impact while stabilizing the shoulder. The activity level of the biceps serves an extremely important function in the late acceleration by decelerating the forceful elbow extension in order to prevent hyperextension of the elbow prior to ball impact (Rhu et el., 1988; Ellenbecker, 1995). This vital function of the biceps reinforces the importance of eccentric muscular training of the biceps in rehabilitation programmes of the shoulder as well as the elbow (Morris *et al*., 1989; Ellenbecker, 1995).

iv. The follow-through phase:

This final phase begins after ball impact (Morris *et al*., 1989; Yoshizawa *et al*., 1987; Ellenbecker, 1995).

High muscular activity levels in the following muscle groups characterize this phase:

- Posterior rotator cuff (40%);
- Serratus anterior (53%);
- Latissimus dorsi (48%); and
- Biceps (34%).

(Rhu *et al*., 1988; Ellenbecker, 1995; Hay & Reid, 1999)

Forceful eccentric muscular contractions are necessary, after the electrical silence of the shoulder musculature during ball impact, to decelerate the humerus and to maintain glenohumeral joint congruity. The distal musculature shows very low activity during the follow-through phase, with the exception of the biceps (Morris *et al*., 1989).

2.4.2 Ground Strokes:

The forehand and the backhand can be broken down into three phases:

i. Preparation phase:

The muscular activity is very low during the preparation phase in both the shoulder and the forearm, with exception of the *wrist extensors* on the forearm (Rhu *et al*., 1988; Schmidt-Wiethoff *et al*., 2003).

ii. Acceleration phase:

Forehand:

High muscular activity levels are found in the:

- Subscapularis;
- Biceps;
- Pectoralis major;
- Serratus anterior;
- Wrist flexors; and
- Pronator teres.

(Rhu *et al*., 1988; Morris *et al*., 1989; Montalvan *et al*., 2002)

It is important to note that vigorous topspin of the forehand is not produced by hyperpronation of the forearm, but rather a low-to-high swing pattern with the entire upper extremity (Groppel, 1986; Schmidt-Wiethoff *et al*., 2003).

Backhand:

High muscular activity levels are present in the:

- Deltoids (88%);
- Supraspinatus (73%);

- Infraspinatus (71%);
- Biceps (45%);
- Latissimus dorsi (45%);
- Serratus anterior (45%); and
- Wrist extensors: the predominant muscle group during this phase.

(Rhu *et al*., 1988; Morris *et al*., 1989; Montalvan *et al*., 2002)

iii. The follow-through phase:

Forehand:

The forehand groundstrokes are characterized by moderately high activity of the following muscle groups:

- Serratus anterior;
- Subscapularis;
- Infraspinatus; and
- Biceps.

(Rhu *et al*., 1988; Montalvan *et al*., 2002)

Backhand:

Moderately high muscular activity was found in the:

- Biceps;
- Middle deltoid;
- Supraspinatus; and
- Infraspinatus.

(Groppel, 1986; Rhu *et al*., 1988; Montalvan *et al*., 2002)

The activity during the follow-through phase was lower than during the acceleration phase (Morris *et al*., 1989).

According to this above-mentioned review, a clinically applicable premise regarding the importance of the rotator cuff, scapular stabilizers (serratus anterior), and the distal forearm musculature (wrist extensors) can be formulated. A working knowledge of the active muscle in the tennis serve and the groundstrokes assists in the formulation of both a preventative conditioning programme as well as a rehabilitation programme for the injured tennis player (Ellenbecker, 1995; Montalvan *et al*., 2002; Schmidt-Wiethoff *et al*., 2003).

2.5 PHYSICAL DEMANDS OF TENNIS

It is generally accepted that the adaptability (learning effect) of a person *rises* with the reduction of the number of factors to which they have to adapt. It is thus very important to direct the athletes' attention to the development of highly specific means of training (Muller et at., 2000). In order to develop a training procedure that is highly orientated toward competition in a specific type of sport, the following conditions are important:

- Thorough knowledge of the specific parameters relevant to performance in the specific sport;
- Scientific tests that cover all the sport-specific parameters and that allow for the classification of the results; and
- Training methods and specific exercises that fulfill the standard criteria for the specific means of training (Menzel, 1990; Muller *et al*., 2000).

When one looks at specific strength and power training, the 'principle of dynamic correspondence' should be taken into consideration during the design of the exercise programme. This implies that the special exercises must be in harmony with those parameters of movement that characterize the structure of competitive technique (Menzel, 1990; Roetert, 2003). The advantage of co-ordinative affinity between training and competitive exercises is that it results in favourable training stimuli in the muscular relevant to the specific movement. It also has the advantage that the specific neural mechanisms are developed, which improve the strength in concrete execution of the movement (Muller *et al*., 2000).

Researchers, such as Roetert & Ellenbecker (1998) characterize tennis as a sport in which players must respond to a continuous series of emergencies. This includes sprinting to the ball, changing direction, reaching, stretching, lunging, stopping and starting. All these characteristics in combination with proper balance and technique throughout a match are critical for optimal performance on the court. Taking all these characteristics into consideration, players must address flexibility, strength and endurance, power, agility and speed, body composition, aerobic and anaerobic fitness in order to improve their tennis game (Menzel, 1990, Roetert & Ellenbecker, 1998; Gokeler *et al*., 2001).

2.5.1 Physiology of flexibility:

Flexibility can be defined as the degree to which the muscles, tendons, and connective tissues around the joints can elongate and bend (Burnham *et al*., 1993; Roy *et al*., 1995; Kirshblum *et al*., 1997; Roetert & Ellenbecker, 1998, Salisbury *et al*., 2003). If skeletal muscles are to perform normally, the brain must be continually informed of the current state of the muscles, and the muscles also have to exhibit healthy tone. Healthy tone is the resistance of the muscle to active or passive stretch at rest (Marieb, 1995).

There are two requirements for healthy tone:

1. The transmission of information from muscle spindles and Golgi Tendon organs to the cerebellum and cerebral cortex; and
2. The stretch reflexes that are initiated by the muscle spindles, which monitor the changes in muscle length (Marieb, 1995).

In tennis a player is required to make shots that places body parts in extreme ranges of motion. If the player can maintain strength throughout a flexible, unrestricted range of motion it will help prevent injury and enhance performance (Roy *et al*., 1995; Roetert & Ellenbecker, 1998; Salisbury *et al*., 2003).

Although flexibility training is an important component of a quality-conditioning programme, it is often overlooked and least adhered to (Kirshblum *et al*., 1997; Salisbury *et al*., 2003). According to Roetert & Ellenbecker (1998), this is due to the following reasons:

- Stretching doesn't always feel good;
- The benefits of flexibility on court is not obvious to the player;
- Most players don't have specific, individualized guidelines on when, how or what to stretch for tennis; and
- Flexibility receives not as much emphasis by coaches than the other components of conditioning.

2.5.1.1 Types of flexibility:

a. Static stretching:

Static flexibility is an indication of the amount of motion that one has around a joint or series of joints *while at rest* (Burnham *et al*., 1993; Kirshblum *et al*., 1997; Roetert & Ellenbecker, 1998; Salisbury *et al*., 2003).

Recommendations for static stretching:

(According to Roetert & Ellenbecker, 1998)

- Warm-up for 3-5 minutes (Burnham *et al*., 1993; Salisbury *et al*., 2003);
- The focus must be on slow, smooth movements with controlled breathing. Firstly, inhale deeply, then exhale as you stretch to the point of motion just short of pain, then ease back slightly. The static stretch position must be held for 15 to 20 seconds as you breathe normally and repeated 2 to 3 times (Burnham *et al*., 1993; Kirshblum *et al*., 1997; Salisbury *et al*., 2003);
- You should not feel intense pain. If a stretch hurts, or has a burning sensation, you are stretching too far;
- Always stretch your tight side first (Burnham *et al*., 1993);

- Perform the stretch only to your limits (Roy *et al*., 1995; Salisbury *et al*., 2003);
- Never lock your joints in a stretch (Burnham *et al*., 1993; Salisbury *et al*., 2003);
- Keep the movement smooth and do not bounce (Burnham *et al*., 1993; Salisbury *et al*., 2003);
- Always stretch the larger muscle groups first, and repeat the same routine each day (Kirshblum *et al*., 1997); and
- An ideal time for stretching is after aerobic activity when the muscles are warm (Burnham *et al*., 1993; Roetert & Ellenbecker, 1998; Salisbury *et al*., 2003).

b. Dynamic stretching:

Dynamic flexibility describes the active range of motion about a joint or series of joints and it represents the amount of movement the player has available for executing serves, groundstrokes and volleys (Burnham *et al*., 1993; Roetert & Ellenbecker, 1998; Salisbury *et al*., 2003).

Dynamic flexibility is limited by the following:

- The joint structure's resistance to motion;
- The ability of the soft connective tissue (muscles and tendons) to deform; and
- The neuromuscular components of the body, including the nerves (Roy *et al*., 1995; Roetert & Ellenbecker, 1998).

Recommendations for dynamic stretching:

(According to Roetert & Ellenbecker, 1998)

- Swing the racquet through each motion arc for the forehand, backhand, and serving movements;
- Reach up with alternate arms, as if you are climbing up a ladder. Incorporate your trunk in each movement;

- Bend to each side, keeping the hands on the hips;
- With the racquet held overhead, hold on to the ends of the racket and bend side to side;
- Still holding the racquet with your hands on the end, rotate your trunk by twisting slowly from side to side;
- Perform a bicycle motion with alternate legs, drawing progressively larger circles; and
- March with alternate legs until the knees are eventually up at nose height.

2.5.1.2 Factors influencing flexibility:

i. Heredity:

Your overall flexibility potential is determined by your body design. Most people tend to be inflexible, though some are loose jointed and hyper-flexible (Roetert & Ellenbecker, 1998; Salisbury *et al*., 2003). The shape and orientation of joint surfaces, as well as the construction and design of the joint capsule, muscles, tendons and ligaments are some of the body designs that influences our flexibility (Burnham *et al*., 1993; Kirshblum *et al*., 1997).

ii. Neuromuscular components:

When a muscle is stretched too quickly, the muscle spindle sends a message to the central nervous system to contract that muscle (Burnham *et al*., 1993). This stretch reflex causes the muscle to shorten and contract and therefore hinders the stretching process. This is the reason why we recommend slow, gradual movements during stretching in order to minimize the reflex action of the muscle spindle and to enhance the stretching process (Burnham *et al*., 1993; Roetert & Ellenbecker, 1998).

iii. Tissue temperature:

Heat increases the elongation and bending properties of soft tissue in the body. By warming up before stretching it raises the body's core temperature and it will give you greater gains in flexibility with less micro trauma to the tissues being stretched (Roetert & Ellenbecker, 1998; Salisbury *et al*., 2003).

2.5.1.3 Areas that need flexibility training:

Tennis places tremendous demands on different body parts in their extremes of motion (Burnham *et al*., 1993; Salisbury *et al*., 2003). For example, the range of motion that the shoulder needs during the external rotation of the serving action stresses the front of the shoulder. Most tennis players are flexible in the external shoulder rotation due to the serving action, but have limited internal rotation on their tennis playing side (Roy *et al*., 1995; Kirshblum *et al*., 1997). Other examples of extreme ranges of motion in tennis includes:

- Lateral movement that stresses the hip and groin;
- Stabilizing muscle actions of the abdominal muscles during the serve; and
- Explosive movement patterns of the calf and achilles tendon (Roetert & Ellenbecker, 1998).

Throughout the match situation, players must generate great speed and force while they are in an outstretched position. It is important to have a conditioning programme that includes flexibility training to ensure that the athlete will have the range of motion needed for optimal performance. In tennis it is essential to have flexibility, combined with the ability to produce power in these extremes of motion (Burnham *et al*., 1993). According to Roetert & Ellenbecker (1998) and Schmidt-Wiethoff *et al*. (2000), stretching alone will not prevent injuries or enhance performance, but a balanced strength throughout a flexible, less restricted range of motion will do so.

a. Shoulder and arm stretches:

i) Trunk and shoulder stretch: (Figure 13)

Focus: Latissimus dorsi, triceps and the inferior capsule of the shoulder.

Start: Stand with both arms overhead, holding the right elbow with the left hand.

Action: The left hand pulls the right elbow in behind the head. While holding this position, bend the trunk to the left side. Repeat to the other side (Burnham *et al*., 1993; Roetert & Ellenbecker, 1998).

***ii) Overhead stretch:* (Figure 14)**

Focus: Intercostal muscles and the inferior capsule of the shoulder.

Start: Stand with both arms overhead, the wrists crossed and the palms together.

Action: Stretch the arms slightly backwards and push them up as high as possible. Bend slightly to either side to increase the stretch to your trunk (Burnham *et al*., 1993; Roetert & Ellenbecker, 1998).

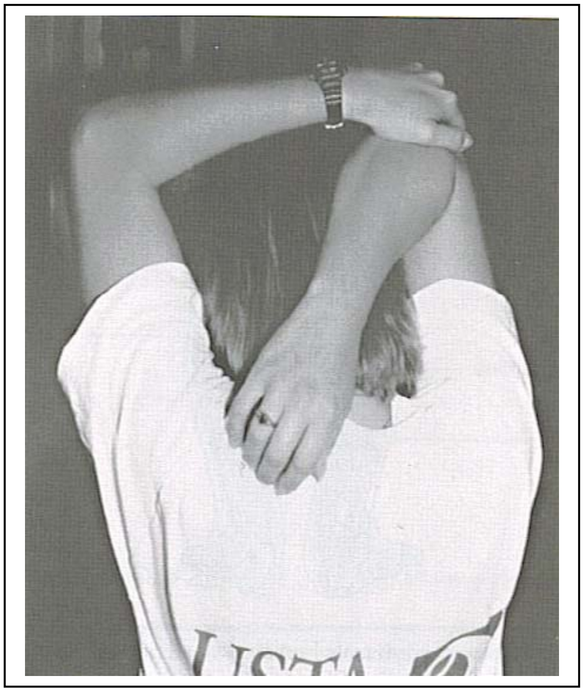


Figure 13: Trunk and shoulder stretch.

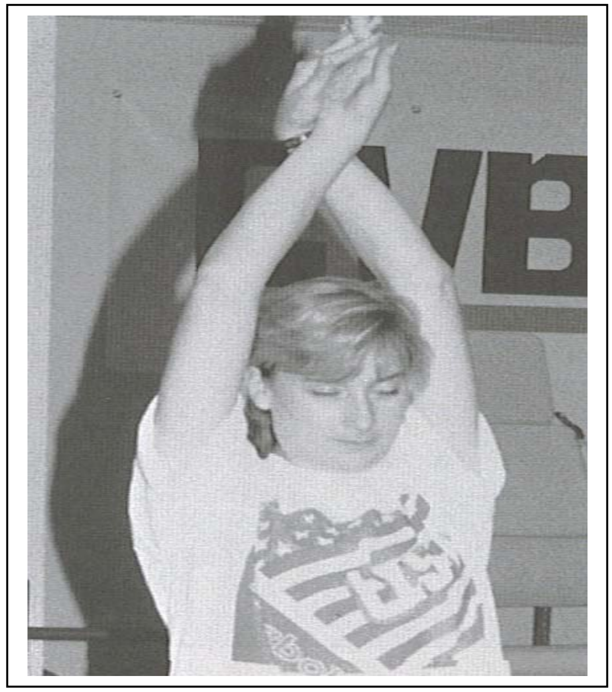


Figure 14: Overhead stretch.

iii) Scapular stretch: **(Figure 15)**

Focus: Rotators of the shoulder and the scapular (upper back) muscles.

Start: Stand by holding your right arm straight in front of you and placing your left arm behind your right elbow.

Action: Pull the right arm across your body with your left hand, but do not allow the trunk to rotate. To help demonstrate this stretch, the athlete can stand against the wall with both shoulder blades touching the wall while performing the stretch (Burnham *et al*., 1993; Roetert & Ellenbecker, 1998).

iv) Shoulder squeeze: **(Figure 16)**

Focus: Shoulders and the front of the chest.

Start: Interlace the fingers behind the head, keeping the elbows straight out to the side and the upper body in an upright, aligned position.

Action: Pull the elbows together behind the head and pull the shoulder blades together in order to create tension through the upper back and shoulders (Burnham *et al*., 1993; Roetert &Ellenbecker, 1998).

Figure 15: Scapular stretch.

Figure 16: Shoulder squeeze.

***v) Forearm flexor stretch*: (Figure 17)**

Focus: Pronators and flexors of the forearm muscles.

Start: The elbow is extended and the forearm supinated (palm up).

Action: Use the opposite hand to stretch the wrist backward while keeping the elbow straight (Roetert & Ellenbecker, 1998).

***vi) Forearm extensor stretch:* (Figure 18)**

Focus: Extensors and supinators of the forearm muscles.

Start: The elbow is extended and the forearm pronated (palm down).

Action: Use the opposite hand to stretch the wrist downward while keeping the elbow straight (Roetert & Ellenbecker, 1998).

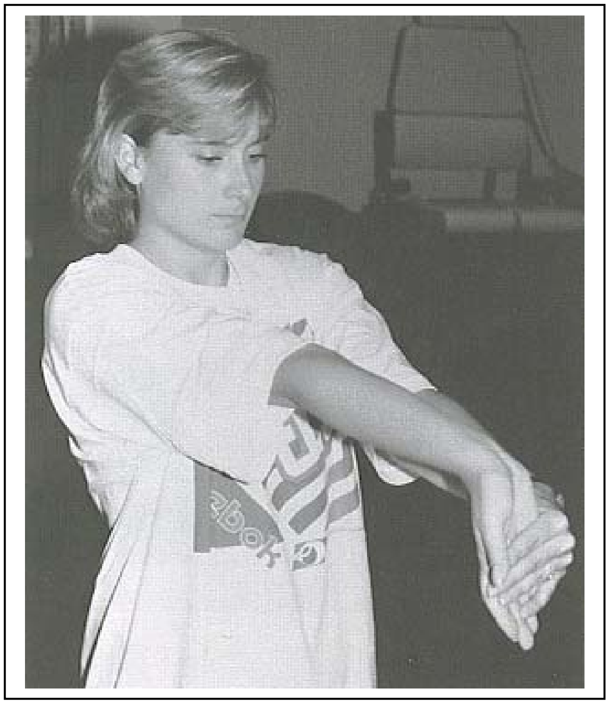


Figure 17: Forearm flexor stretch.

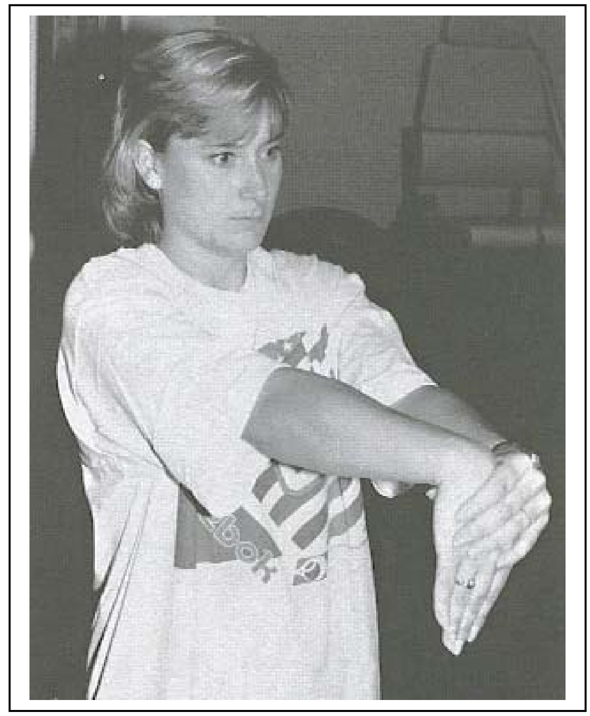


Figure 18: Forearm extensor stretch.

2.5.1.4 Benefits of Flexibility:

a. It allows sport-specific strengthening in extreme motions (Roetert & Ellenbecker, 1998);

b. It accommodates the stresses on the body by helping the tissue to distribute the impact of shock and force loads more effectively (Roy *et al*., 1995; Kirshblum *et al*., 1997; Salisbury *et al*., 2003);

c. It lightens the intensity of work of the opposing muscle groups by providing less restricted motion (Roetert & Ellenbecker, 1998);

d. Flexibility enhances blood supply and tissue nourishment (Kirshblum *et al*., 1997);

e. It allows good form and posture without compensating from other body segments (Burnham *et al*., 1993; Roy *et al*., 1995); and

f. It helps to overcome imbalances created by tennis and by other daily activities (Salisbury *et al*., 2003).

2.5.2 Strength and Endurance:

According to Costill & Fox (1969), Kraemer *et al*. (1995) and Kraemer *et al*. (2003) muscular power is a very important aspect in tennis and therefore resistance training became an important tool to optimize the neuromuscular performance factors related to the primary strokes. The classical model of periodization of resistance training manipulates the intensity and volume of exercise over time with the main intention of minimizing boredom, prevention of overtraining and to reduce injuries (Matveyev, 1981; Fleck, 1999; Kraemer *et al*., 2003). It was typically used by strength and power sports to peak physical performance for major competitions. Due to the fact that not all sports are pure strength and power sports, and also may have multiple competitions and long seasons, a nonlinear or undulating model has been proposed. In this model different training sessions could be rotated over a 7- to 10- day cycle (Costill & Fox, 1969; Kraemer *et al*., 2003). A recent review of the literature done by Fleck (1999) supported the hypothesis that periodization of resistance training can result in greater maximal strength gains and may even result in greater motor performance adaptations in comparison to the traditional resistance-training programmes with limited variation in stimuli over long-term periods. Many resistance-training programmes provide only a limited variation in the volume and intensity used during training (Kraemer *et al*., 2003).

2.5.2.1 Weight Training:

In sport, weight training has become so important that it seems incredible that the prejudices that once surrounded its use ever existed. One of the outstanding reasons for the improvement in sport performance over the last thirty years has been the increased use of weight training as an essential part of the athlete's conditioning programme (Kirkley & Goodbody, 1986; Meister; 2000; Schmidt-Wiethoff *et al*., 2000; Roetert, 2003). Due to the importance of muscular power in tennis, resistance training has become a very important training tool to optimize the neuromuscular performance factors related to the primary strokes in tennis (Kraemer *et al*., 2003). Certain sports benefit more from weight training than others, but the most important aspect is that these gaps in some of the sports needs to be filled by people qualified in the science of weight training in order to benefit the sport (Roetert, 2003). The weight- training programme needs to be adapted to the *specific activity*, because the needs of all sports differ. The training programme of a tennis player will be totally different to the type of training of a shot-putter (Kirkley & Goodbody, 1986; Kraemer *et al*., 2003).

In modern sport, including tennis, weight training has become more valuable than before due to the increase of people devoting themselves to excellence in tennis. Professional people in this field must preferably examine the training schedule carefully. It is important to determine the type of exercises, sets and repetitions that are suitable for tennis (Kirkley & Goodbody, 1986; Roetert, 2003).

a. The scientific basis of weight training:

Traditional weight training is based on the principle of 'progressive overload'. In order to raise the level of strength and stamina, the body must be subjected to an increased resistance through heavier weights, higher repetitions or longer or more frequent training sessions (Kirkley & Goodbody, 1986; Kraemer *et al*., 2003). A good example of "progressive overload" is the lesson from the Greek legend of Milo of Croton. Milo uses to carry a little calf daily, and as the calf grew so did his strength. When the calf reached the age of four years, Milo was still able to carry the bull because his body adapted to the greater demands placed on it (Costill & Fox, 1969; Kirkley & Goodbody, 1986).

The following demonstrates the basic principles of weight training:

- In order to increase strength or size, the body must be asked to perform tasks, which it previously did not achieve;
- The intensity of training must be increased gradually and steadily;
- Training must be regular; and
- The exercises must be specific (Kirkley & Goodbody, 1986; Ellenbecker *et al*., 2002; Kraemer *et al*., 2003).

The importance of specificity can't be stressed enough (Costill & Fox, 1969; Matveyev, 1981; Kirkley & Goodbody, 1986; Kraemer *et al*., 2003; Roetert, 2003). Various types of training have been subjected to research in recent years as the desire for improvement has escalated (Kirkley & Goodbody, 1986; Kraemer *et al*., 2003). One thing that strongly emerges, is the fact that training must be geared to the particular sport for which the athlete is training for (Kirkley & Goodbody, 1986; Fleck, 1999; Kraemer *et al*., 2003). In tennis, using weights will help to develop explosive power and speed on court, muscle strength as well as muscle endurance. What is important is that the athlete should be carefully analysed in order to develop a programme according to his/her abilities. Only then can be determined the kind of exercise, the number of repetitions and the severity of the activity appropriate to the athletes needs. One of the reasons that makes weight training so popular is because it is so versatile and can be adapted to so many requirements (Kirkley & Goodbody, 1986; Roetert, 2003; Salisbury *et al*., 2003).

Periodisation is very important in any sport, especially in tennis where the players have to peak more than once a year and where the competition seasons are throughout the year (Fleck, 1999; Kraemer *et al*., 2003). According to research done by Kraemer *et al*. (2003), periodisation of resistance training produced greater magnitudes of improvement in strength and sport-specific motor performance than the traditional resistance training programmes where there are limited variations in volume and intensity of training. The major difference between these two training principles was the variation in intensity during each week of the periodized programme. The effect of greater strength and power with periodized training is most likely due to the ability to recruit more fast- twitch motor units with the inclusion of the heavier loading (Sale, 1988; Schmidtbleicher, 1988; Kraemer *et al*., 2003; Roetert, 2003). According to studies done by Anderson & Kearney (1992) and Kraemer *et al*. (2003) individuals that were exposed to heavier loads during training experienced greater improvement in maximal strength performance. Also, heavy resistance training shows to be effective in increasing strength in female athletes over a 6-month training period (Brown & Wilmore, 1974; Ellenbecker *et al*., 2002; Kraemer *et al*., 2003).

b. The Physiology of Muscle Growth:

Psychological inhibition and learning factors can greatly modify one's ability to express muscular strength in the early phase of training. Though, the ultimate limit for strength is determined by anatomical and physiological factors within the muscle (McArdle *et al*., 1991).

i. Muscular Hypertrophy:

A fundamental biological adaptation that can be viewed to an increase in workload is the increase in skeletal muscle size. This compensatory adjustment leads to an increase in the muscle's capacity to generate tension (Willmore, 1974; McArdle *et al*., 1991). According to Gollnick (1983) and Hakkinen (1988) the muscular growth in response to overload training occurs primarily from an enlargement or *hypertrophy* of individual muscle fibers. They found that the fast-twitch muscle fibers of weight lifters were 45% larger than those of healthy sedentary people and endurance athletes.

ii. Hyperplasia:

The question whether the actual number of muscle cells increases with training is often raised. If it does take place, to what extent does it contribute to muscular enlargement in humans? (McArdle *et al*., 1991). Cross-sectional studies of body builders with relatively large limb circumference and muscle mass failed to prove that these athletes possessed a significant hypertrophy of individual muscle fibers (MacDougall *et al*., 1980). This leaves open the possibility of hyperplasia in humans with resistance training. It suggests either an inherited difference in muscle fiber number or that muscle cells may adapt differently to the high volume, high intensity training used by body builders compared with the typical low-repetition, heavy load system favoured by weight and power athletes (Larsson & Tesch, 1986; Tesch, 1988). According to MacDougall (1984) the enlargement of the existing individual muscle cells makes the greatest contribution to muscular size with overload training.

2.5.3 Body Composition:

Another change that takes place with training, is the reduction in body fat percentage. According to McArdle *et al*. (1991) adipose tissue increases in two ways:

a. Cell hypertrophy: Existing fat cells are enlarged or filled with more fat; or
b. Fat cell hyperplasia: The total number of fat cells increase.

When a person reduces body size, there is a decrease in fat cell size, but no change in the total cell number (McArdle *et al*., 1991). An increased calorific output through endurance type exercise provides a significant option of unbalancing the energy balance equation to bring about weight loss as well as a desirable modification in body composition (Craig, 1983). The performance of conventional resistance training programmes combined with calorific restriction, results in the maintenance of lean body mass compared with a programme that relies only on diet (McArdle *et al*., 1991).

According to Konig *et al*. (2001) and Kraemer *et al.* (2003) the progressive adaptation of top ranked players induced by years of training and match play included changes in the following:

- heart size;
- maximum oxygen intake;
- onset of lactate production;
- heart rate;
- blood pressure;
- hormonal regulation;
- functional and structural alterations in the conducting arteries;
- bone density; and

- muscle mass of the dominant arm.

2.5.3.1 Characteristics of female and male tennis players:

It is well documented by Willoughby (1993) that Woman's upper body strength differs from their lower body strength in terms of their initial strength and their ability to adapt to training.

a. Anthropometrical Aspects:

There are no general differences between male and female up to the age of approximately 12 years (Willoughby, 1993; Meister, 2000), although several structural, functional, mental and physical differences can be observed in early childhood (ITF Manual).

Table 3: The differences in weight distribution between males and females (ITF Manual).

	MALE	FEMALE
Bones:	20%	15%
Muscle:	40%	36%
Fat tissue:	20%	30%
Internal organs:	12%	12%
Blood:	8%	7%

Table 4: The differences in bones and joints between males and females (ITF Manual).

ASPECT	MALE	FEMALE
Height:	Taller.	Shorter: 10-12cm.
Weight:	Heavier.	Lighter: 10-15kg.
Limbs:	Limbs, hands and feet are longer.	Limbs, hands and feet are 10% shorter which positively affects their flexibility and

		agility, and due to the shorter stroke lever arm, the power of the stroke is reduced.
Trunk:	Longer: 38%.	Shorter: The center of gravity is lower.
Skeleton:	It looks as if the limbs overhang.	It looks as if the trunk overhangs.
Spine:	Upper part is less pronounced. Lower part is shorter and the curvature less pronounced.	Upper part is more pronounced. Lower part is longer and the curvature more pronounced.
Shoulders:	Greater shoulder width with better-developed muscles – more power in the serve.	Less shoulder width with less developed muscles – less power in the serve.
Arms:	The formative arm structures at the elbows make them more suited for throwing actions.	The formative deviations in the arm-structures at elbow levels make them less suited for throwing actions.
Back:	Wider and stronger: 39cm.	Narrower and weaker.
Pelvis:	Narrower, less flat and weaker.	Wider, flatter and stronger. The disposition of the pelvic bones does not allow elevation of the legs as males. Therefore females have less effectiveness in speed and jumping actions.
Legs:	No genus valgus.	Different lines of support which tends to converge towards the knees (genus valgus).

Table.5: The differences in muscles between males and females (ITF Manual).

ASPECT	MALE	FEMALE
Weight of muscles mass (30years):	More: 35kg.	Less: 23kg (50%less).
Total muscular power:	20-35% greater.	20-35% less.
Muscular development:	There is more muscular tone and mass for it is dependent on the testosterone levels.	There is less muscular tone and mass for it is dependent on the testosterone levels.
Muscular elasticity:	Less.	More.
Type and number of muscular fibers:	More fibers, greater percentage of oxidative fibers and bigger oxidative and glycolytic capacity.	Less fiber.

Table 6: The differences in fat tissue between males and females (ITF Manual).

ASPECT	MALE	FEMALE
Percentage of fat tissue:	Usually less body fat percentage. In athletes the fat percentage range between 6 and 20%.	Usually more body fat percentage. In sportswomen it can range between 12 and 30%.
Distribution of fat tissue:	Accumulated in the abdomen and stomach.	Accumulated in the gluteus and hips.
Fat deposit:	Less: Body appears more muscular.	More: Body appears less muscular.

b. Biological aspects:

The mean heart rate in trained tennis players aged between 20 and 30 years ranges between 140 and 160 beats per minute during singles tennis matches. This indicates an overall intensity of 60 to 70% of their VO2-max (Elliott *et al*., 1985; Bergeron *et al*., 1991; Groppel & Roetert, 1992; Konig *et al*., 2001; Kraemer *et al*., 2003). In professional players, this corresponds to an ergometrically-determined workload within an aerobic/anaerobic transition range on a treadmill of 13km/h for women and 14km/h for men at a 1.5º slope (Konig *et al*., 2001). Despite the start and stop nature of tennis, heart rates during match play are not distinct variations in accordance with the duration of the match (Elliott *et al*., 1985). During fast and long rallies the heart rate can increase up to 190 – 200 beats per minute (Bergeron *et al*., 1991). However, these highly intense periods are relatively short, and good condition assures a fast recovery rate. This is advantageous for the concentration and the preparation for the next rally (Konig *et al*., 2001).

The heart and the blood circulation display different characteristics in males and females (Konig *et al*., 2001; ITF Manual). Due to the lower cardiac volume of females in comparison with males, a lower level of oxygen occurs in the circulatory system of woman (Groppel & Roetert, 1992). The respiratory frequency in females is higher than in males due to the fact that females have different thoracic breathing and also a lower respiratory volume. The pulmonary capacity increases rapidly in both genders up to the age of 12. It then increases very slowly or remains the same in females. Females need the same amount of oxygen as males in order to perform the same activity, although it is harder for females to achieve the same performance due to their lower pulmonary capacity (Groppel & Roetert, 1992; ITF Manual).

Table 7: The differences in the respiratory system between males and females (ITF Manaul).

ASPECT	MALE	FEMALE
Weight of lungs (kg):	1.35	1.05
Pulmonary volume:	10% higher	10% lower
Pulmonary volume (sq. m):	90	80
Air volume or vital capacity (L):	5.5	4.1
Maximum oxygen intake (L/min):	3.1	2.4
Maximum oxygen per beat (cc):	15-20	10-13
Maximum respiratory rhythm (per min):	40	46
Maximum volume of deep breath (L):	5.0	3.5
Maximum respiratory capacity forced breathing (L/min):	170	100
Maximum respiratory volume per minute normal breathing (L/min):	110 (25% more)	90

Table 8: The differences in the circulatory system between males and females (ITF Manual).

ASPECT	MALE	FEMALE
Heart weight (g):	350	300
Heart capacity (cc):	600-800	500-600
Heart size (cc):	750	550
Volume maximum heart beat (cc):	210	160
Volume maximum heart per minute (L/min):	37	25
Maximum beats (min):	190	180
Haemoglobin (%g):	16	14
Blood volume (ml/kg):	70-80	60-70
Blood total volume (L):	5.0	3.8

c. Developmental aspects:

In a newborn baby the bones of males are heavier than females and the growing proportion remains similar until puberty (Marieb, 1995). However, females reach puberty earlier than males and therefore their bodies mature earlier (Roetert *et al*., 1995, ITF Manual). The performance of females is lower than males due to the specific functional and anatomical differences, which can be noticed from the age of 7-8 years old. Due to the differences in development, females achieve their maximum physical performance round about the age of 15-16 years while men achieve it at 18-20 years of age. Due to the lower physical capacity of the female athlete, the effort that she would have to put in, in order to perform the same given task as a male, would be much bigger (Roetert *et al*., 1995; ITF Manual).

Table 9: Characteristics that highlights differences in development between males and females (ITF Manual).

FEMALE DEVELOPMENTAL STAGE	**CHARACTERISTICS**
Overall growth period is shorter.	Puberty is reached earlier and the final structure is attained earlier.
Second period of growth is shorter.	Maximum annual growth in height is 9cm for males and 7.7cm for females.
Faster sexual maturity.	The duration between the second stage of development of the body and the second period of growth is 6 months in females and 13 months in males.

Table 10: Specific characteristics of the female body: Anatomical and functional differences in systems and organs of the body (ITF Manual).

ASPECT	CHARACTERISTICS
Blood circulation:	Up to the age of 8 years, the size of the heart is similar in both genders. Between 8 and 13 years it is bigger in females, and after 13 years it is considerably smaller. The heart efficiency in the post-puberty period is lower in females and thus has a higher frequency of beats than males.
Respiratory system:	The respiratory system of females is fully developed between 14 and 15 years as opposed to males at 18 years.
Metabolism:	The body weight of females is lower than males due to the higher quantity of fat deposits.
Oxygen consumption:	Females have lower oxygen consumption than males.
Oxygen in muscles:	The oxygen usage in muscles of males is more efficient than females.
Motor development:	From the age of 4 to 6 years the differences in motor development become evident. From the age of 8 years, males displays better performance in power, agility, speed, endurance and reflexes. During puberty (12 – 15 years) these differences increases even more.

d. Psychological aspects:

According to research done by the International Tennis Federation (ITF manual) females have a higher desire to learn during practices, they are more disciplined and they have a better ability to mix with and be part of the group. Women display a greater need for a coach and other persons and are also more open and thankful for advice given to them. They have also shown that sportswomen are more diligent and meticulous than sportsmen.

Table 11: The differences in motivation and interest between males and females (ITF Manual).

ASPECT	MALES	FEMALES
Intensity of games and activities preferred:	Active games and competition.	Passive or quit games with less muscular activity.
Types of games and activities preferred:	Throwing, running, speed and power games.	Jumping, balancing, rhythmic exercises.
Volume of physical activities during puberty:	Higher.	Lower.
Goals of practice:	They want to impress with their physical strength, ability and intelligence.	They want to show their femininity and also the characteristics of their own personality.

Table 12: The differences in psychological variables between males and females (ITF Manual).

ASPECT	MALES	FEMALE
Anxiety:	Males suffer less from anxiety states than females and react with less sensitivity, impatience and in a less nervous way.	Females suffer from anxiety states more frequently than males and they react with more sensitivity, impatience and in a more nervous way.
Intellectually:	No difference.	No difference.
Aggressiveness:	More physical.	More verbal, acute and intellectual.
Decision making:	More confident.	Less confident when young and they often look for external help when in trouble.
Mental stability:	Less susceptible psychologically and less variable.	More susceptible psychologically and more variable, tending to depression and states of nervous excitement.
Confidence:	More self-confidence.	Less self-confidence and more insecure. More worried about their health and losing their femininity.
Individualism:	Less individualistic.	More individualistic.
Dependency:	More independent and less influenced.	Less independent, more influenced, more sensible and more adaptable.

2.6 INJURIES IN TENNIS PLAYERS

A good example of a tennis injury occurred at the 1996 Wimbledon Championships, when Borris Becker hit a forehand service return and injured his wrist to a shocking extent following that one shot. Borris then stated during an interview that he had hit that forehand service return the same way he had hit it thousands and thousands of times before. Borris was correct in analysing his injury, that it had occurred in spite of not doing anything differently. This also holds true for most injuries in tennis players (Roetert & Ellenbecker, 1998).

2.6.1 Causes of injuries in Tennis Players:

Most injuries in tennis players are typical *overuse* injuries (Priest & Nagel, 1976; Kibler & McQueen, 1988; Roetert & Ellenbecker, 1998; Schmidt-Wiethoff *et al*., 2000; Gokeler *et al*., 2001; Roetert, 2003). They result form repetitive stresses and minor traumatic events, such as the effects on the shoulder due to serving thousands of times, or the influence on the knee after playing hundreds of points with pivots, turns and aggressive stops and starts. Overuse injuries occur due to the fact that tennis players exert and produce forces in repetitive patterns that cause minor traumas and tissue breakdown (Roetert & Ellenbecker, 1998, Meister, 2000).

Tennis is a combination of endurance and power. Every match or training session involves between 300 and 500 bursts of effort, each requiring power and co-ordination of movement (Turner & Dent, 1996). According to Kibler & McQueen (1988) and Ellenbecker (1995), there are specific physiological and mechanical stresses imposed on the shoulder girdle in tennis that causes characteristic anatomic adaptation. This can lead to subsequent overuse injuries (Ellenbecker, 1995; Schmidt-Wiethoff *et al*., 2000; Kraemer *et al*., 2003). Serves may be delivered at speeds of 176km/h and the players have to change direction frequently and withstand forceful impacts with the ball (Turner & Dent, 1996). The shoulder is one of the most mobile joints in the entire human body and due to its large range of motion, it can become injured easily during tennis play (Hay &

Reid, 1999; Gokeler *et al*., 2001; Montalvan *et al*., 2002). The glenuhumeral joint consists of a ball (humerus) and socket (glenoid) without the benefit of a deep socket that is found in the hip joint. Therefore, the muscles and the ligaments that surround the shoulder must work harder in order to keep the ball in the socket (Ellenbecker *et al*., 2002). Especially during rapid movements, which in tennis, occur as fast as 2500 degrees per second. This speed is similar to the rotation of the wheels on a bike traveling 51.2km/h and 417 times faster than the rotation of the second hand on a clock! (Ellenbecker *et al*., 2002; Sonnery-Cottet *et al*., 2002).

The modern tennis game encourages the use of maximum effort in order to increase ball speed off the racquet and this results in larger forces being absorbed by the body, more specifically, the shoulder (Turner & Dent, 1996; Schmidt-Wiethoff *et al*., 2003). 70-80% of all tennis injuries are caused by *overuse* (Ellenbecker, 1995; Turner & Dent, 1996; Kraemer *et al*., 2003). Two such injuries that are common in tennis are *rotator cuff tendonitis* and *humeral epicondylitis* (Priest & Nagel, 1976). Ellenbecker (1995) found in his study that there was a 63% higher incidence of shoulder injuries among players with tennis elbow than among players with no history of tennis elbow. Many young players are actively involved in intensive tennis training programmes and according to Turner & Dent (1996) the growing body is particular susceptible to damage. Due to the larger forces being absorbed by the body and the growing body being susceptible to injuries, as mentioned above, it necessitates that we carefully investigate tennis injuries. More specifically, we need to investigate the warning signs, their treatment and also *what the coaches and trainers can do to reduce the risk of injury* (Turner & Dent, 1996; Gokeler *et al*., 2001; Schmidt-Wiethoff *et al*., 2003).

Two of the most common shoulder injuries in tennis involve the *rotator cuff* and the *biceps long head tendon* (Reece *et al*., 1986; Schmidt-Wiethoff *et al*., 2000; Gokeler *et al*., 2001; Montalvan *et al*., 2002; Sonnery-Cottet *et al*., 2002). During the overhead upper extremity movements of the serve, the rotator cuff and the biceps tendon are placed in a compromising position between the humeral head and the coracoacromial arch. Neer (1983) and Ellenbecker (1995) described the mechanism of subacromial impingement of the rotator cuff tendons under the coracoacromial arch as the *primary factor* that contributes to overuse shoulder injuries. A progression has been reported in the literature which starts at shoulder impingement in the initial phase of oedema and tendon inflammation and progresses to bursal side (superior surface) partial rotator cuff tears and subsequent full-thickness tears (Bigliani *et al*., 1992; Meister & Andrews, 1993; Montalvan *et al*., 2002).

Another factor that can lead to tendinous inflammation and progress to an undersurface (articular side) rotator cuff tear is the intrinsic tendon overload caused by high-intensity decelerative eccentric muscular contractions of the posterior rotator cuff during the follow-through phase of the serve (Meister & Andrews, 1993; Ellenbecker, 1995; Sonnery-Cottet *et al*., 2002).

The rotator cuff has got a stabilizing function in resisting:

- Anterior translation;
- Internal rotation;
- Horizontal adduction; and
- Distraction at the glenohumeral joint during the follow-through phase.

(Montalvan *et al*., 2002; Sonnery-Cottet *et al*., 2002)

This stabilizing function of the rotator cuff can be magnified in the shoulder in the case of subtle instability (Meister & Andrews, 1993; Ellenbecker, 1995; Montalvan *et al*., 2002; Schmidt-Wiethoff *et al*., 2003). Anterior instability of the glenohumeral joint can be caused by attenuation of the glenoid labrum as well as the capsuloligamentous complex (Wilk & Arrigo, 1993). Progressive attenuation of these static stabilizers occurs with overhead activities like the serve and the smash (Jobe & Bradley, 1989; Sonery-Cottet *et al*., 2002). The attenuation of the static stabilizers causes a greater demand on the dynamic stabilizers, which involves the rotator cuff and the biceps long head. This can result in tendon inflammation and progressive rotator cuff disease (Wilk & Arrigo, 1993; Gokeler *et al*., 2001). The presence of instability in the tennis player's shoulder can cause tensile injury to the rotator cuff and it also subjects the rotator cuff to secondary impingement or compressive lesions (Jobe & Bradley, 1989; Gokeler *et al*., 2001). According to Ellenbecker (1995) both subacromial and articular surface impingement have been reported in throwing shoulders where instability is present.

According to Groppel (1986), Groppel & Roetert (1992) and Ellenbecker *et al*. (2002) it is clear that non-optimal timing and a lack of whole-body contributions to force generation and deceleration, subject an individual's shoulder and elbow to overuse injury. This can be seen in the presence of increased, as well as overlapping muscular activity patterns across the four stages in the tennis serve (as described in 2.4.1).

Tennis injuries can be divided into two categories: *acute* and *chronic. Acute injuries* refer to a new injury or complaint from the time it occurs and the short time following the start of the injury (Fox *et al*., 1993; Gokeler *et al*., 2001). An example of an acute injury is an ankle sprain. *Chronic injuries* repeat themselves due to continued tennis play or the lack of proper rehabilitation (Fox *et al*., 1993; Gokeler *et al*., 2001). An example of a chronic injury would be a tennis elbow that has been present for a year or two and flares up during long, gruelling tournaments. Acute injuries are much easier to treat than chronic injuries and if you take care of them initially, you can prevent them from becoming chronic (Roy & Irvin, 1983; Roetert & Ellenbecker, 1998; Montalvan *et al*., 2002).

2.6.2 Occurrence of Tennis Injuries:

Analysis of epidemiological studies done in tennis **(Table 13)** shows a high prevalence of shoulder and elbow injuries. According to this research, shoulder injuries ranges from 10% to 30% among elite junior tennis players, and 80% of all tennis injuries are caused by overuse.

Table 13: Epidemiology of upper extremity overuse injuries in tennis players.

Population	Age (years)	Sample size	Incidence (%)	Reference
Shoulder:				
• Elite juniors	11-14	97	14	Kibler *et al*., 1988
• Elite juniors	16-20	66	18	Reece *et al*., 1986
• Elite juniors	12-19	-	24	Lehman, 1988
Elbow:				
• Recreational adults		231	17	Priest *et al*., 1977
• Recreational adults		534	18	Hang & Peng, 1984
• Recreational adults		150	21	Kitai *et al*., 1986

It is important that the rehabilitation programme focuses on the relationship between injuries within the upper extremity. In a study done on world-class tennis players, 74% of men and 60% of women had an injury in the dominant arm that affected their tennis game (Priest & Nagel, 1976; Brooks, 2001). In the research done by Priest *et al*. (1980) they illustrated the interplay and the relationship between overuse injuries in the upper extremity. They discovered that there was a 63% higher incidence of shoulder injuries among tennis players with a history of tennis elbow than among players without a history of tennis elbow. This reinforces the concept of a rehabilitation programme that addresses the entire upper extremity kinetic chain in the tennis player (Priest *et al*., 1980; Brooks, 2001; Rubin & Kibler, 2002; Schmidt-Wiethoff *et al*., 2003).

2.6.3 Prevention of Shoulder Injuries:

As mentioned earlier, most of the injuries that occur in tennis are due to *overuse*. The training programme and specific exercises are therefore very important in order to minimize the risk of injury.

Due to the nature of tennis, for example, the intrinsic tendons get overloaded from high-intensity decelerating and eccentric muscular contractions of the posterior rotator cuff during the follow-through phase of the serve (Gokeler *et al*., 2001; Schmidt-Wiethoff *et al*., 2003). This can lead to tendinous inflammation and progress to an undersurface (articular side) rotator cuff tear if the muscles are not strong enough (Ellenbecker, 1995; Gokeler *et al*., 2001). The rotator cuff muscles are the primary muscles preventing the humerus head from slipping out of the glenoid cavity during play and is active during all tennis strokes (Roetert & Ellenbecker, 1998; Sullivan, 2001). Resulting from its repetitive muscle work, one common shoulder injury is damage to the rotator cuff. The tendon becomes inflamed due to the heavy workload of the tennis strokes. Tendons generally heal slowly, because their blood supply and healing potential are less than those of muscles (Roetert & Ellenbecker, 1998; Schmidt-Wiethoff *et al*., 2000; Sullivan, 2001; Ellenbecker *et al*., 2002).

Another very important factor that makes the tennis player vulnerable to overuse injuries in the shoulder is muscle imbalance (Schmidt-Wiethoff *et al*., 2000; Ellenbecker *et al*., 2002; Schmidt-Wiethoff *et al*., 2003). Typically in tennis players, the anterior muscles of the shoulder and the chest (pectoralis and anterior deltoids) are stronger than the rotator cuff and the upper back muscles that support the scapula (Roetert & Ellenbecker, 1998). It is therefore very important that the tennis training programme focuses on the strengthening of the rotator cuff and the upper back muscles (Plancher *et al*., 1995; Roetert & Ellenbecker, 1998; Ellenbecker *et al*., 2002).

2.6.3.1 Precautions in strengthening the rotator cuff muscles:

i) Avoid using heavy weights:

By using heavy weights while strengthening the rotator cuff muscles, the body will be forced to use larger muscle groups, such as the trapezius and the deltoid. Therefore it is recommended that the athletes use low-resistance, high-repetition format in strengthening the rotator cuff muscle (Plancher *et al*., 1995; Roetert & Ellenbecker, 1998; Kraemer *et al*., 2003).

ii) Minimize the lifting of weights overhead:

In tennis, the shoulder is seldom lifted overhead, even on the serve. The following six positions can be used to specifically train the rotator cuff muscles in a save position. These positions are all demonstrated in the tennis specific exercises in Chapter 2.7:

a. Prone horizontal abduction (p91);
b. 90º-90º external rotation (p93);
c. Scaption (empty can) (p93);
d. External shoulder rotation with rubber tubing (p94);
e. Internal shoulder rotation with rubber tubing (p95); and
f. External shoulder rotation with abduction (p96) (Roetert & Ellenbecker, 1998).

2.6.3.2 Sport-specific Training Programmes:

It is important that the training programme of the athlete is sport-specific. These exercises will form the base for preventing injuries (Hay & Reid, 1999; Sullivan, 2001).

Additional preventative tennis specific exercises that will reduce the risk of injury, are discussed in Chapter 2.7.

2.6.4 Rehabilitation of the Injured Shoulder:

Thorough understanding of the biomechanical stresses and anatomical adaptations in tennis players can enhance diagnosis and treatment of these injuries (Ellenbecker, 1995; Ellenbecker *et al*., 2002). The formulation of a comprehensive rehabilitation programme that focuses on the upper extremity kinetic chain, serves to restore normalized joint arthrokinematics and enables a full return to the repetitive musculoskeletal demands of tennis (Ellenbecker, 1995; Soderberg, 1997; Meister, 2000; Ellenbecker *et al*., 2002).

Until recently, the role of the scapula in the clinical evaluation and rehabilitation of the shoulder and upper extremity disorders has received very little attention. Research shows that it is important to diagnose and treat the shoulder in the context of the kinetic chain (Soderberg, 1997; Rubin & Kibler, 2002). A kinetic chain is a series of links and segments activated sequentially in a co-ordinated fashion in order to generate and transmit forces to accomplish a specific function (Feltner & Dapena, 1989; Dillman, 1990; Ellenbecker *et al*., 2002; Rubin & Kibler, 2002;). In activities that involve a throwing action, like tennis, there is an open-ended kinetic chain with proximal-to-distal muscle activation and co-ordination of body segments that produces interactive movements at the terminal segment (wrist and hand) (Rubin & Kibler, 2002). In the throwing motion, the sequence of link activation begins with the creation of a ground reaction force as a result of the foot and leg pushing against the ground. This force is then dramatically increased as it is transmitted through the knees and the large muscles of the legs, through the hips and into the lumbopelvic region and the rest of the trunk. The proximal segments, the legs and the trunk, produce half of the energy (51%) and force (54%) that is ultimately delivered to the distal end of the kinetic chain (Atwater, 1971; Rubin & Kibler, 2002; Schmidt-Wiethoff *et al*., 2003). The scapula and the glenuhumeral joint function both as a link and a segment in the kinetic chain, rather than in isolation. They act to increase the kinetic energy and force generated to the distal segments where the smaller muscles can position the arm and the hand in order to control the throw. This activation sequence allows for proximal stability and distal mobility in the active kinetic chain (Meister, 2000; Ellenbecker *et al*., 2002; Rubin & Kibler, 2002). According to Rubin & Kibler (2002) a kinetic chain varies with the position and the environment in which the activity is being performed. The activities can generally be divided into two categories:

- Sitting *versus* standing; and
- Land-based *versus* water-based.

When an individual reaches, pushes or pulls from a sitting position, there is less energy and force contributed by the legs than executing force from a standing position. The primary generator for the upper extremity motion is the initiation of trunk stabilization (Rubin & Kibler, 2002; Schmidt-Wiethoff *et al*., 2003). In the case of aquatic sports, there are also additional considerations that are important in evaluating the symptoms of the shoulder and also during the rehabilitation process (Atwater, 1971; Ellenbecker *et al*., 2002; Schmidt-Wiethoff *et al*., 2003).

2.6.4.1 Physical Examination of the Shoulder:

It is important to perform the evaluation in the context of the kinetic chain in order to elucidate functional deficits that are related to patho-anatomy, patho-physiology or patho-mechanics (MacDougall *et al*., 1991). The evaluation must be complete and specific about the *primary diagnosis* that may be causing secondary symptoms. An example is that rotator cuff tendonitis may be caused by either instability due to capsular laxity *or* abnormal scapular mechanics (MacDougall *et al*., 1991; Schmidt-Wiethoff *et al*., 2000; Rubin & Kibler, 2002). In order to accomplish this, the clinician must take an accurate history, evaluate alterations in local and distant anatomy, scapular mechanics, and kinematics of the entire kinetic chain (Rubin & Kibler, 2002).

While discussing the *clinical history*, the following aspects of the shoulder should be observed:

i. The patient's posture:

This includes:

- The position of the neck and head, trunk and the shoulders. Postural alignment can further be assessed by applying an axial load on top of the shoulders while the patient attempts to prevent accentuation of lumbar lordosis. (Schmidt-Wiethoff *et al*., 2000; Ellenbecker *et al*., 2002; Rubin & Kibler, 2002);
- Lumbopelvis stability and strength. These are evaluated with a modified Trendelenberg test where the patient is asked to balance and squat, standing on each leg independently (Sullivan, 2001); and
- Trunk strength. This is determined by having the patient in a supine position, lowering each leg from an elevated position while attempting to prevent lumbar lordosis (MacDougall *et al*., 1991; Rubin & Kibler, 2002).

ii. Scapulohumeral Rhythm:

This is observed from behind as the patient slowly raises and lowers the arms in abduction and flexion. By doing this, the concentric and eccentric function of the scapular stabilizers can be assessed. Weakness is frequently seen during the eccentric phase (Gokeler *et al*., 2001; Rubin & Kibler, 2002).

There are three distinct patterns of scapular dyskineses that are commonly observed:

Type I: Winging occurs at the inferior medial border;

Type II: This involves the entire medial border of the scapula; and

Type III: The superior medial border is prominent (Kibler *et al*., 2003).

To date, no reproduceable association between specific shoulder pathological diagnoses and specific dyskinesis patterns has been seen (Meister, 2000; Ruben & Kibler, 2002).

iii. Glenohumeral range of motion:

This range of motion must be observed to document all abnormal movements of the scapula during internal and external rotation at 90º of abduction. If any pain occurs during abduction or forward flexion, the examiner must attempt to correct the problem by substituting for the lower trapezius while inhibiting the upper trapezius. This test is called the *scapular assistance test (SAT)* and is considered positive if the pain is eliminated or significantly reduced by this manoeuvre. A positive SAT- test is an indication of proximally derived dyskinesis with secondary subacromial impingement (Kibler, 1998; Schmidt-Wiethoff *et al*., 2000; Rubin & Kibler, 2002).

iv. Scapular positioning:

The *lateral scapular slide test* can be used as a static measurement to determine scapular positioning (Kibler, 1998; Sullivan, 2001). This test involves measuring the side-to-side difference from the spinous process of the seventh thoracic vertebra to the infero-medial border of the scapula in the following three positions:

- *Position 1*: With the arms at the sides;
- *Position 2:* With the hands on the pelvic rim; and
- *Position 3*: With the arms in 90º abduction with the shoulders internally rotated and the forearms pronated.

A difference of 1,5cm is considered as clinically significant (Rubin & Kibler, 2002; Sullivan, 2001).

v. Testing of the rotator cuff:

The muscles of the rotator cuff can be tested manually with:

- Resisted external rotation in adduction and 90º of abduction for the infraspinatus and the teres minor;
- Resisted elevation in the scapular plane for the supraspinatus; and

- The Napoleon test for the subscapularis (Gokeler *et al*., 2001; Burkhart & Tehrany, 2002; Ellenebecker *et al*., 2002; Montalvan *et al*., 2002).

If significant weakness occurs either with or without associated pain, the test should be repeated with repositioning of the scapula (Burkhart & Tehrany, 2002; Rubin & Kibler, 2002).

vi. Lesions of the superior labrum:

A passive distraction test can be used to assess the integrity of the superior labral attachment to the glenoid (Figure 19) (Rubin & Kibler, 2002).

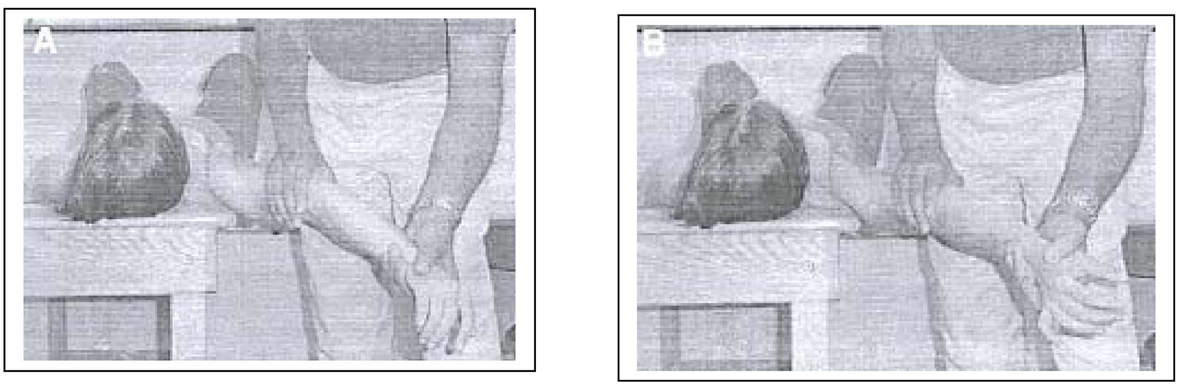


Figure 19: Passive distraction test. (a) Arm is positioned overhead in the plane of the trunk, the elbow is extended and the forearm in neutral or slight supination. (b) Forearm is gently pronated (Rubin & Kibler, 2002).

In this passive distraction test, the patient is placed in the supine position with the shoulder off the examining table, the arm is flexed overhead in the plane of the trunk with the elbow extended, and the forearm is held in a neutral position or in slight supination. The forearm is then gently pronated without rotation of the humerus. If pain is elicited, it is an indication of the anterior and posterior locations of the lesion (Burkhart & Tehrany, 2002; Rubin & Kibler, 2002).

vii. Labral pathology:

Labral pathology is diagnosed by assessing clicks and grinds that are associated with rotation and capsular loading, joint-line palpation, modified Jobe relocation test (apprehension suppression test), and the Mayo shear test, which is specifically for posterior superior labral abnormality, or internal impingement (Rubin & Kibler, 2002). Alteration of posterior pain, in the position of the throwing arm, with the arm 90º abducted and 90º externally rotated, by scapular retraction and depression is also an indication of posterior superior labral pathology (Burkhart & Tehrany, 2002).

viii. Capsular laxity and instability:

Capsular laxity and instability can be evaluated with the load and shift test in the anterior, posterior and inferior directions with varying degrees of rotation and elevation. Anterior and posterior apprehension, apprehension suppression and also pain associated with the relocating testing can be noted. (Burkhart & Tehrany, 2002; Rubin & Kibler, 2002; Wright & Matava, 2002). The examiner should be aware of the fact that capsular laxity varies with age, chosen activity of sport, temporal relationship with the last workout and in some cases the dominant arm. Normal variances in capsular laxity must be borne in mind (Rubin & Kibler, 2002; Wright & Matava, 2002). Harryman *et al.* (1992) reported anterior and posterior translation of almost 8mm both anteriorly and posteriorly in asymptomatic volunteers.

2.6.4.2 Principles of Functional Rehabilitation:

The goal of functional rehabilitation is to *restore normal function* instead of just eliminating the symptoms. It is based on the basic principles of the kinetic chain, with restoration of normal anatomy, physiology, biomechanics and kinematics (Kibler & Livingston, 2001). Research done by Hodges (1999) showed that before either arm or leg movement is initiated, the transversus abdominus is activated first. This increases the intra-abdominal pressure in anticipation of the action. It is important that, during the initial phase of rehabilitation, the distant deficits should be corrected first. This also involves the restoration of flexibility and strength in the hip, trunk and the periscapular regions (Rubin & Kibler, 2002). Local deficits, such as a shortened pectoralis minor or subscapularis muscle-tendon unit, should be corrected within the patient's tolerance (Hodges, 1999; Kibler & Livingston, 2001).

Control of the proximal segments of the kinetic chain should be accomplished during the early stages of rehabilitation. The process of restoration of normal posture, hip and trunk extension and scapular retraction should be achieved in an upright position with the feet on the ground in order to restore normal physiology and proprioception (Rubin & Kibler, 2002). Thus, all exercises should be initiated with the patient in the "ideal position". This includes good postural alignment, a level pelvis, and the scapula retracted and depressed. Sequential distal segment activation is then facilitated with those exercises that connect the hip and the trunk with the scapula, and the scapula with the rotator cuff (Hodges, 1999; Kibler & Livingston, 2001; Rubin & Kibler, 2002).

As proximal stability is being regained, rehabilitation of the scapula should be incorporated. This includes scapular retraction and depression in order to restore the normal force couples, and thereby:

1. decreasing acromial tipping;
2. providing a stable muscle base for shoulder function;
3. positioning the glenoid for optimal stability and rotator cuff function; and
4. enabling the scapula to funnel and transmit the forces from the trunk to the upper extremity as part of the kinetic chain (Burkhart & Tehrany, 2002; Rubin & Kibler, 2002).

Once the scapula is normal, glenohumeral rehabilitation can proceed. This includes the restoration of capsular mobility and rotator cuff activation to restore normal compression (Burkhart & Tehrany, 2002). As soon as the patient can isolate the specific rotator cuff muscles, rehabilitation should be integrated into the context of the kinetic chain. In order to decrease the shear forces on the joint while enhancing strength gains, it is recommended that *closed-chain* exercise protocols be used (Kibler & Livingston, 2001; Rubin & Kibler, 2002).

Finally, plyometric exercises involving all kinetic-chain segments are incorporated in the final phase of rehabilitation. These exercises will then restore the required power and activate stretch-shortening cycles as soon as there is appropriate anatomical healing, satisfactory range of motion and when the integrity of the kinetic chain has been restored (Hodges, 1999; Rubin & Kibler, 2002).

2.6.4.3 Guidelines for Core-based Functional Rehabilitation:

1. Proximal stability must be regained before distal mobility is sought.

2. The focus should be on scapular position and control, with tightened abdominal muscles that holds the spine in a neutral position, and correct postural alignment.

3. The patient must be able to identify and isolate the specific muscles to be strengthened.

4. Muscle groups should be trained in a co-ordinated, synchronized pattern to re-establish the force couples for scapular stabilization and elevation in order to control pain, decrease subacromial impingement and to facilitate muscle re-education.

5. Exercises should be relatively pain free. It is very difficult to progress a painful joint. If pain occurs during rehabilitation, it is a sign that either the wrong

exercises are being done at that time in the recovery process *or* the exercise is being done incorrectly.

6. The quality of the exercise is more important than the quantity being performed. The patient should therefore focus more on muscle control than on the number of repetitions being done.

7. Exercises should be done until the muscle fatigues. This is the point at which biomechanics become abnormal, and it is better to stop rather than to do the remaining repetitions incorrectly.

8. The progression in the strengthening programme is isometric to eccentric to concentric training.

9. Closed-chain exercises always preceed open-chain exercises.

10. As more progressive exercises are added, the easier ones should be eliminated to prevent boredom on the part of the patient.
    (Scripture *et al*., 1894; Scripture *et al*., 1897; Hellebrandt *et al*., 1950; Hellebrandt & Waterland, 1962; Stromberg, 1986; Kibler & Livingston, 2001; Rubin & Kibler, 2002; Roetert, 2003; Schmidt-Wienhoff *et al*., 2003)

2.6.4.4 Phases of Rehabilitation:

The recovery phase can be divided into early and late segments to allow for varied goals in this prolonged period of rehabilitation (Rubin, 2000; Kibler & Livingston, 2001).

i) Acute Phase:

This phase is relatively short and in the postoperative patient it ranges from approximately 1 to 3 weeks. The goals are to:

- control the pain and inflammation by means of immobilization, modalities, analgesics and non-steroidal anti-inflammatory drugs (Kibler & Livingston, 2001);
- clear soft tissue restrictions and postural abnormalities with soft tissue mobilization and stretching (Rubin, 2000; Rubin & Kibler, 2002);
- begin muscle re-education with postural- and core strengthening exercises. This includes lumbopelvic stabilization, scapular positioning (retraction and depression), and also closed-chain rotator cuff exercises (Kibler & Livingston, 2001; Rubin & Kibler, 2002); and
- begin active and active-assisted range of motion exercises, starting in the scapular plane or forward flexion (Rubin, 2000; Rubin & Kibler, 2002).

The ***criteria*** used to advance from the acute phase to the early recovery phase are as follows:

- minimal pain on range of motion;
- reasonable lumbopelvic strength;
- adequate scapular control;
- adequate soft-tissue healing; and
- adequate release of soft-tissue restrictions (Rubin & Kibler, 2002; Sonnery-Cottet *et al*., 2002).

ii) Early Recovery Phase:

This phase usually lasts for 3 to 6 weeks post-operatively, and the goals are to:

- increase range of motion and flexibility with passive range of motion exercises and joint mobilization as well as active-assisted and active range of motion exercises;
- increase strength, control and endurance; and
- restore the normal kinematics (Rubin, 2000; Rubin & Kibler, 2002; Sonnery-Cottet *et al*., 2002).

The ***criteria*** used to advance from the early recovery phase to the late recovery phase are as follows:

- pain-free range of motion;
- almost the full range of motion and flexibility;
- improved strength and control; and
- improved kinematics (Rubin & Kibler, 2002; Sonnery-Cottet *et al*., 2002).

iii) Late Recovery Phase:

This phase usually extends from 6 to 12 weeks post-operatively, and the goals are to:

- restore the full range of motion and flexibility with joint mobilization, soft tissue work, and stretching in all planes;
- increase strength, power and endurance with exercises that stress the core-based muscle synergy; and
- advance eccentric and concentric scapular stabilization exercises (Rubin, 2000; Sullivan, 2001; Rubin & Kibler, 2002;).

The ***criteria*** used to advance from the late recovery phase to the functional phase are as follows:

- full range of motion;
- normal kinematics; and
- approximately 75% of the normal strength, power and endurance (Sullivan, 2001; Rubin & Kibler, 2002).

iv) Functional Phase:

This phase usually begins 3 months post-operatively. In this phase it is wise to take advantage of the knowledge and the skills of coaches and trainers in the development of sport-specific progressions. The goals are to:

- restore the sport and work specific kinematics;
- increase strength, power, and endurance to a functional level for the chosen activity of the patient; and
- restore the required activity-specific co-ordination, speed and quickness (Rubin, 2000; Burkhart & Tehrany, 2002; Rubin & Kibler, 2002).

During this functional phase, plyometric exercises, drills for agility and co-ordination, and also conditioning exercises that are specific for the patient's chosen sport or activity are pursued (Hodges, 1999; Rubin & Kibler, 2002).

For the patient to advance from this phase, the patient must have:

- normal upper quarter kinematics within the context of the kinetic chain;
- a normal range of motion and flexibility for the specific sport or activity;
- approximately 90% strength; and
- symptom-free activity or sport-specific drills (Sullivan, 2001; Rubin & Kibler, 2002; Roetert, 2003).

2.7 TENNIS SPECIFIC SHOULDER EXERCISES

2.7.1 Rotator cuff programme:

As mentioned earlier, the rotator cuff plays an important role in tennis and it is therefore very important to strengthen all these muscles (Meister, 2000; Schmidt-Wiethoff *et al*., 2000; Montalvan *et al*., 2002). The following exercises are used to develop the rotator cuff muscles. It is recommended that these exercises be initially performed with a 0.5 to 1.0kg weight, because these muscles are very small. Also, start with two to three sets of 12 to 15 repetitions to promote endurance to these muscles first. If a weight is used that is too heavy, the player may compensate and perform the exercises using the larger muscles groups that are already developed (Roetert & Ellenbecker, 1998; Montalvan *et al*., 2002). According to Roetert & Ellebecker (1998) even the strongest and the largest athletes use a maximum of 2 to 2.5kg for these exercises strengthening the rotator cuff muscles.

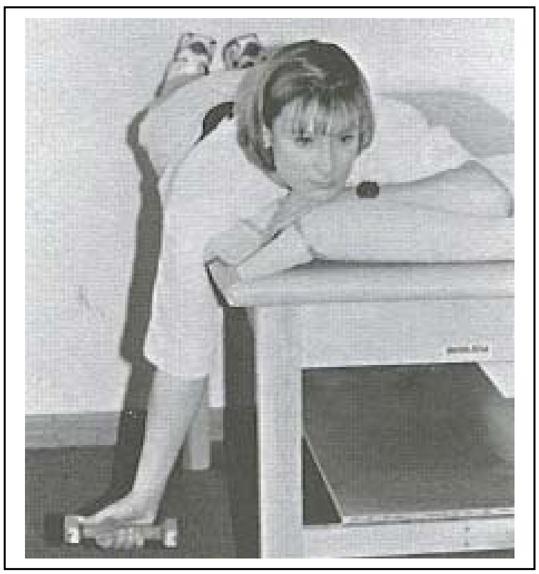
a. Prone horizontal abduction: (Figure 20)

Focus: Strengthens the rotator cuff, rhomboids, trapezius and the posterior deltoids.

Start: Lie on the stomach on a table with the racket arm hanging straight down towards the floor with the thumb pointing outwards.

Action: Raise the arm outwards to the side at a 90º angle until almost parallel to the floor. Lower it back to the starting position and repeat (Roetert & Ellenbecker, 1998; Burkhart & Tehrany, 2002).

(a)



(b) 

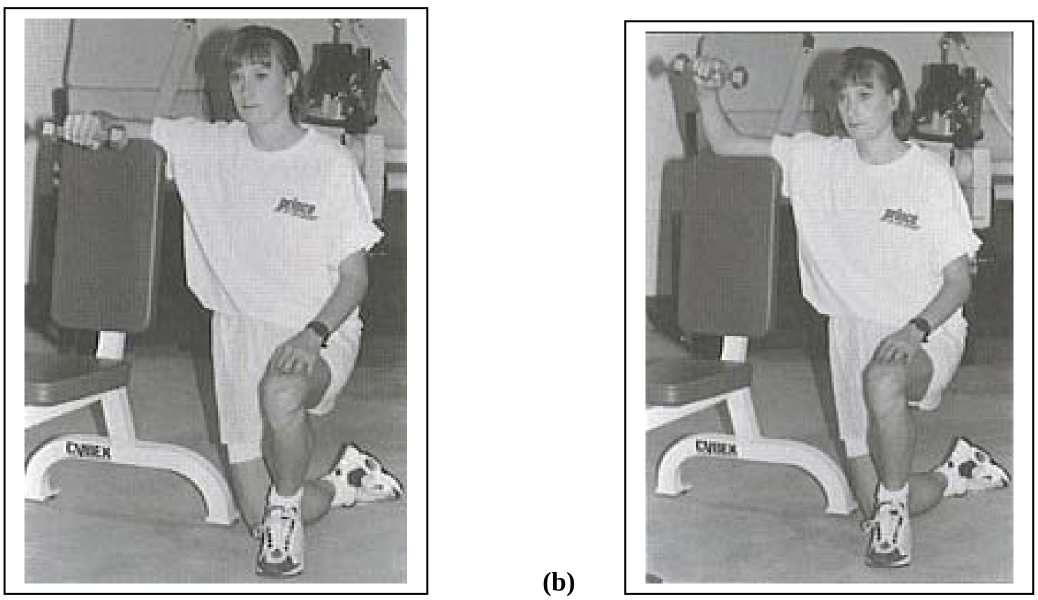
Figure 20: Prone horizontal abduction. (a) Starting position. (b) Action (Roetert & Ellenbecker; 1998).

b. 90º-90º External shoulder rotation: (Figure 21)

Focus: Develops the external rotators of the shoulder.

Start: Kneel and place the arm on an incline bench. Keep the upper arm parallel to the ground and the forearm perpendicular to the upper arm at 90º.

Action: Maintain a right angle at the elbow and externally rotate the forearm until it points to the ceiling at 90º abduction. Slowly lower the arm and return to the starting position (Roetert & Ellenbecker, 1998; Burkhart & Tehrany, 2002; Montalvan *et al*., 2002).



(a) **(b)**

Figure 21: 90º-90º External shoulder rotation. (a) Starting position. (b) Action (Roetert & Ellenbecker, 1998).

c. Scaption (Empty Can): (Figure 22)

Focus: Strengthens the supraspinatus muscle and the deltoid.

Start: Stand with the elbow straight and the thumb pointing towards the ground.

Action: Raise the arm up to shoulder level on a diagonal plane, 30º - 45º to the side. Slowly lower the arm and repeat.

Note: Be sure not to raise the arm above shoulder height (Roetert & Ellenbecker, 1998).

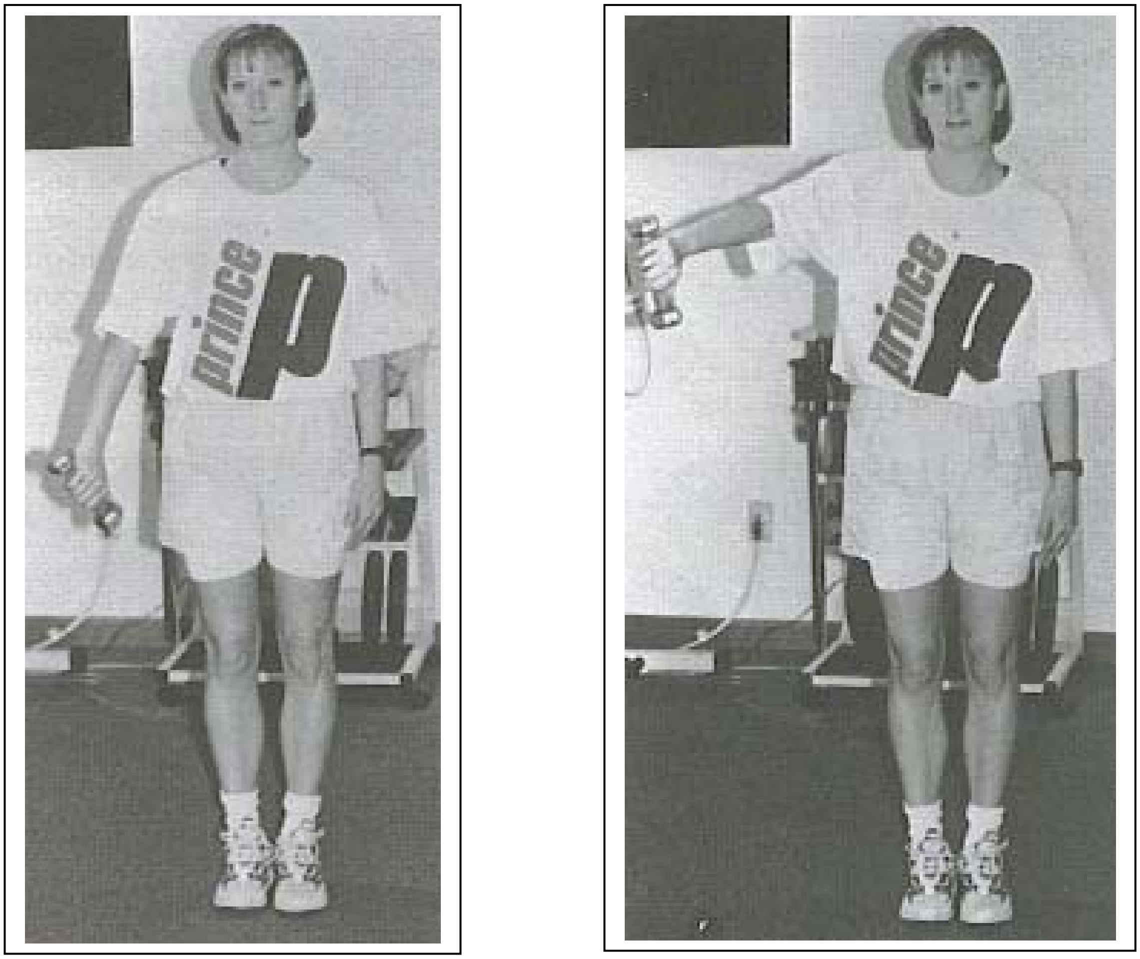


Figure 22: Scaption (Empty Can). (a) Starting position. (b) Action (Roetert & Ellenbecker, 1998).

d. External shoulder rotation with rubber tubing: (Figure 23)

Focus: Develops external rotator strength of the shoulder.

Start: Secure the rubber tubing at waist height to a doorknob. Stand sideways to the door with the racket arm furthest from the door. Place a small, rolled towel under the racket arm and squeeze.

Action: Hold the rubber tubing in the racket hand and start with this hand close to the stomach. Rotate the hand and the forearm away from the stomach until the hand and forearm are straight out in front of the elbow, pulling the tubing for resistance. Return the arm to the starting position and repeat. The elbow must be kept at a 90º-angle throughout the exercise (Roetert & Ellenbecker, 1998; Burkhart & Tehrany, 2002; Montalvan *et al*., 2002).

Figure 23: External shoulder rotation with rubber tubing. (a) Starting position. (b) Action (Roetert & Ellenbecker, 1998).

e. Internal shoulder rotation with rubber tubing:

Focus: Develops internal rotator strength of the shoulder.

Start: Secure the rubber tubing at waist height to a doorknob. Stand sideways to the door with the racket hand closest to the door. Place a small, rolled towel under the racket arm and squeeze.

Action: Grip the rubber tubing in the racket hand and start with the arm and forearm in a 90º-angle straight out in front of the elbow. Rotate the hand and forearm in towards the stomach. Return to the starting position and then repeat. The elbow must be kept at a 90º-angle throughout the exercise (Roetert & Ellenbecker, 1998; Ellenbecker *et al*., 2002).

f. External shoulder rotation with abduction: (Figure 24)

Focus*:* Strengthens the rotator cuff in a position specific to the tennis serve.

Start*:* Secure the rubber tubing at waist height to a doorknob. Stand facing the door with the shoulders abducted to 90º, about 30º in front of you on a diagonal. Use the opposite hand to support the upper arm.

Action: Grip the tubing in the racket hand and rotate the hand back until it reaches nearly vertical. Return to the starting position and then repeat (Roetert & Ellenbecker, 1998; Burkhart & Tehrany, 2002).

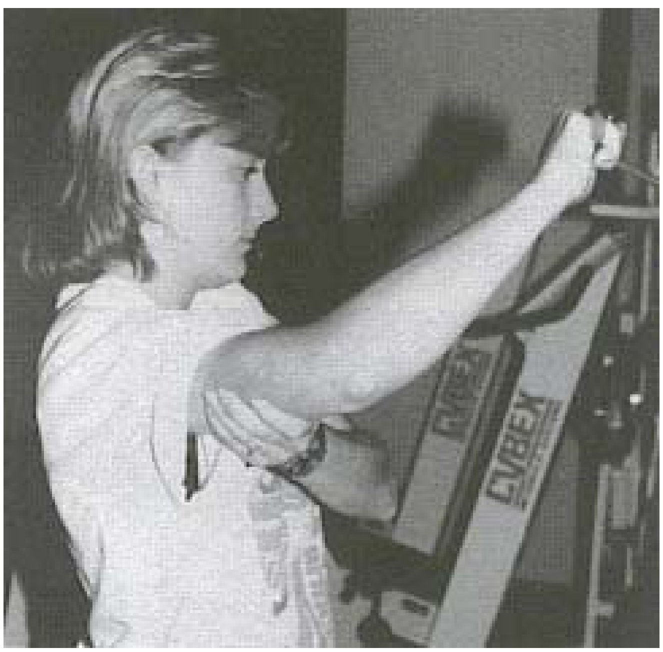


Figure 24: External shoulder rotation with abduction (Roetert & Ellenbecker, 1998).

2.7.2 Additional tennis specific upper body exercises:

a. Seated row: (Figure 25)

Focus: To develop the rhomboids, trapezius, posterior deltoids and the biceps.

Start: Sitting position with the knees slightly flexed and the hands holding onto a cord or band device, cable column or a seated row machine.

Action: Keep the upper body erect and avoid leaning backwards. Then pull the band handles toward the chest and the upper abdomen area while keeping the elbows close to the sides. Return slowly to the start position and then repeat the action (Roetert & Ellenbecker, 1998; Burkhart & Tehrany, 2002; Ellenbecker *et al*., 2002).

Figure 25: Seated row (Roetert & Ellenbecker, 1998).

b. Bent over row:

Focus: Strengthens the latissimus dorsi, rhomboids, trapezius and the posterior deltoids.

Start: Bend over a bench with the non-active knee and hand supporting on the bench. Keep the back flat and supported by tightening the abdominal muscles and the buttocks.

Action: Start by holding the dumbbell in the hand with the arm fully extended below the shoulder. Lift the dumbbell by raising the elbow to the ceiling until the dumbbell touches the side of the abdomen (Roetert & Ellenbecker, 1998; Burkhart & Tehrany, 2002).

c. Push-ups:

Focus: General conditioning and strengthening of the upper body.

Start: The hands are placed shoulder-width apart with the body in a straight line from the toes to the head.

Action: Slowly lower the body down until the upper arm is parallel to the ground. Push upward until the elbows are completely straight and round the back outward like a cat. The rounding motion at the end of the push-up is very important for it increases the work by the muscles that stabilize the scapula (Roetert & Ellenbecker, 1998; Ellenbecker *et al*., 2002).

Note: If a player has a history of shoulder problems or experience any shoulder pain, only lower the body one-half of the way down.

d. Lat pull down:

Focus: Strengthens the latissimus dorsi and the bicep muscles.

Start: Use either a lat pull down machine, overhead cable or rubber tubing. Reach upward and grasp the handles with a wide grip.

Action: Pull the bar, cable or tubing down by bringing the bar in front of the head toward the middle of the chest. Slowly return the bar to the starting position and repeat (Roetert & Ellenbecker, 1998).

e. Chest press:

Focus: Strengthens the pectoralis major and pectoralis minor, serratus anterior, triceps and the anterior deltoids.

Start: Lie on your back on a narrow bench with the arms externally rotated at a 90º-angle to the torso.

Action: Keep the wrist directly over the elbows without locking the elbows and then extend the hands upwards toward the ceiling. While the hands extends upward, round the shoulders by pushing the hands as far as possible away from the body. *This extra motion works the serratus anterior muscle, which supports the scapula while playing tennis* (Roetert & Ellenbecker, 1998; Ellenbecker *et al*., 2002; Roetert, 2003).

f. Biceps curl:

Focus: Strengthens the bicep brachi, brachialis and the brachioradialis.

Start: Stand with the feet shoulder width apart while holding the dumbbell with the hands supinated.

Action: Keep the elbows at the sides while bringing the weights upwards towards the shoulders. Make sure not to arch the back or to lean backwards during this exercise. Slowly lower the hands to the starting position, making sure not to hyperextend or to lock the elbows (Roetert & Ellenbecker, 1998; Burkhart & Tehrany, 2002).

g. Triceps extension:

Focus: Strengthens the triceps muscle.

Start: Lie in a supine position holding a dumbbell in the hand with the shoulder and elbows bent 90º. Use the other hand to support the upper arm and to keep it still throughout the exercise.

Action: Straighten the elbow by raising the hand and the weight upward and make sure that the elbows do not lock (Roetert & Ellenbecker, 1998; Burkhart & Tehrany, 2002; Roetert, 2003).

h. Shoulder shrugs:

Focus: Develops the upper trapezius and the scapula stabilizers.

Start: In a standing position, keep the feet shoulder width apart, arms at the sides and holding the dumbbells in the hands.

Action: Keep the arms at the sides, raise the shoulders upward towards the ears and squeeze the scapulas together while rolling the shoulders backwards. Return to the starting position by slowly lowering the shoulders and then repeat (Roetert & Ellenbecker, 1998; Ellenbecker *et al*., 2002).

i. Shoulder punches:

Focus: Strengthens the serratus anterior, which is an *important scapula stabilizer.*

Start: In a supine position, keep the shoulder flexed to 90º and the elbow straight. Hold a medicine ball or a dumbbell in line with the shoulder.

Action: Keep the elbow straight and raise the hand toward the ceiling as far as possible. Slowly return the hand to the starting position and repeat. The hand should only move about 15cm up and down (Roetert & Ellenbecker, 1998; Roetert, 2003).

j. Prone fly:

Focus: Works the upper deltoid, rhomboids and trapezius.

Start: Lie in a prone position on a narrow bench with the feet off the ground.

Action: With a dumbbell in both hands, extend the arms from the sides at a right angle (90º). Maintain the right angle at the shoulders while raising the arms until they are nearly parallel to the ground (Roetert & Ellenbecker, 1998; Burkhart & Tehrany, 2002).

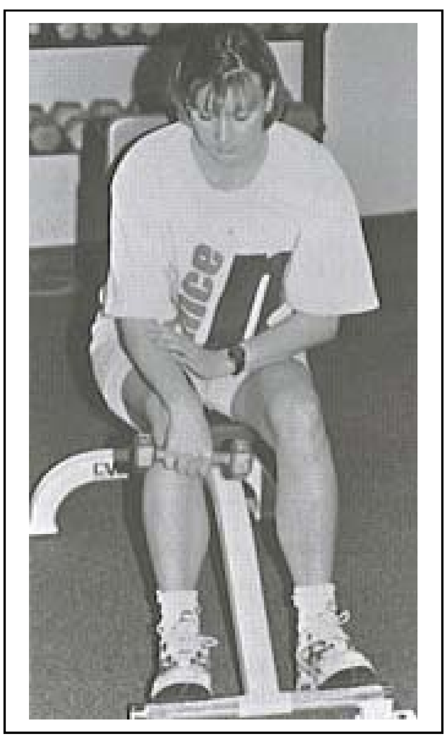
2.7.3 Forearm and Wrist Programme:

a. Wrist Curls: (Figure 26)

Focus: Works the wrist and finger extensors.

Start: Sit down on a chair with the elbow flexed and the forearm resting on a table or over the knee. With the palm facing downwards, let the wrist and the hand hang over the edge.

(a)



(b)

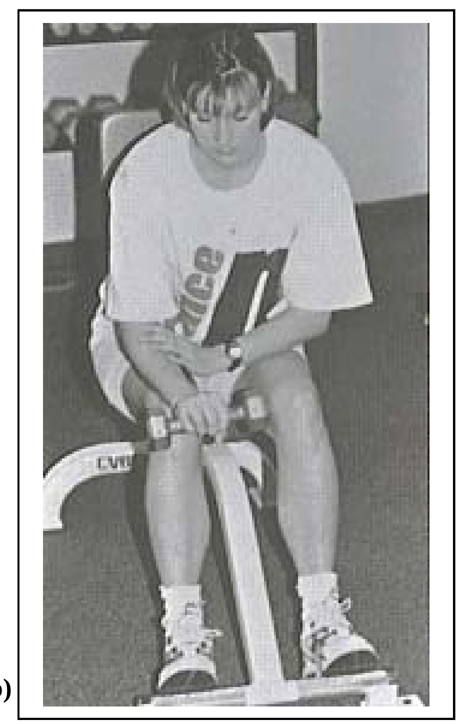


Figure 26: Wrist Curls. (a) Starting position. (b) Action (Roetert & Ellenbecker, 1998).

Action: Slowly curl the wrist and the hand upwards while the opposite hand stabilizes the forearm. Make sure that only the wrist is moving and not the elbow. Raise the hand slowly, hold for 2 seconds and then slowly lower the weight again and repeat (Roetert & Ellenbecker, 1998; Burkhart & Tehrany, 2002; Roetert, 2003).

b. Wrist Curls: Flexors: (Figure 27)

Focus: Strengthens the wrist and the finger flexors.

Start: Sit down on a chair with the elbows flexed and the forearm resting on a table or over the knee. With the palm facing upwards, let the wrist and the hand hang over the edge.

Action: Slowly curl the wrist and the hand upward while the opposite hand stabilizes the forearm. Make sure that only the wrist is moving and not the elbow. Raise the hand slowly, hold for 2 seconds and then slowly lower the weight again and repeat (Roetert & Ellenbecker, 1998; Ellenbecker *et al*., 2002).

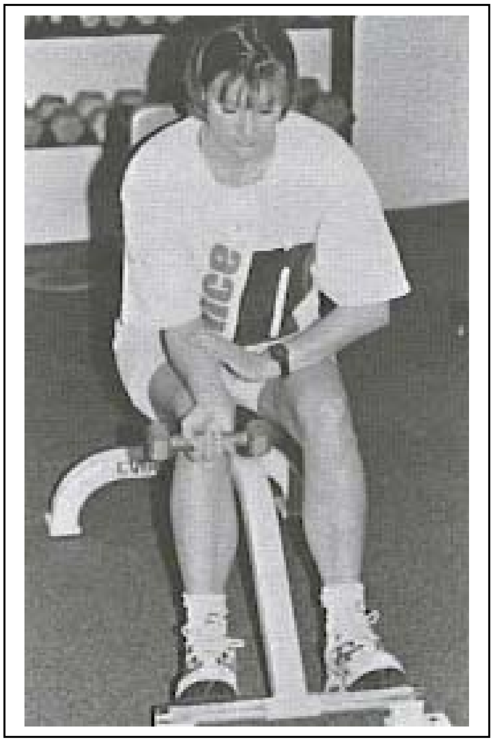


Figure 27: Wrist Curls: Flexors (Roetert & Ellenbecker, 1998).

c. Forearm pronation:

Focus: Strengthens the forearm pronators.

Start: Sit down on a chair with the elbow flexed and the forearm resting on a table or over the knee. Let the wrist and the hand hang over the edge of the table or knee. Use a dumbbell with a weight at only one end and start the exercise with the palm facing upwards and the handle horizontal.

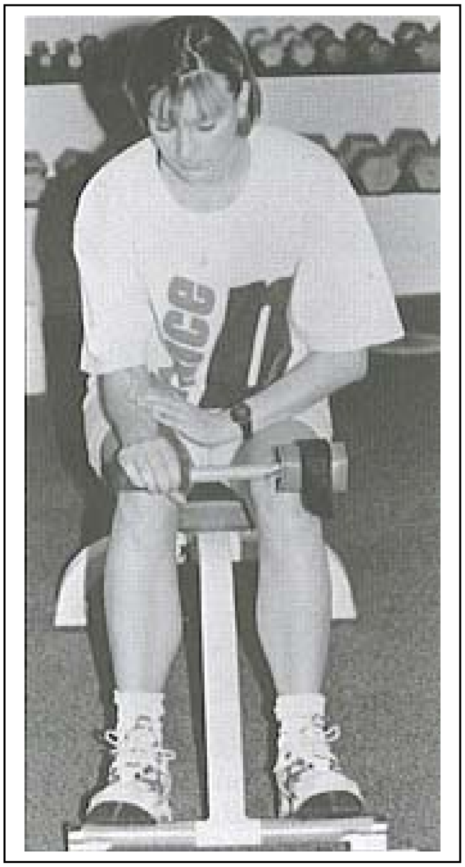
Action: Slowly raise the weight by rotating the forearm and the wrist to a vertical position (Roetert & Ellenbecker, 1998; Burkhart & Tehrany, 2002).

d. Forearm supination: (Figure 28)

Focus: Strengthens the forearm supinators.

Start: Sit down on a chair with the elbow flexed and the forearm resting on a table or over the knee. Let the wrist and the hand hang over the edge of the table or knee. Use a dumbbell with a weight at only one end and start the exercise with the palm facing downwards.

Action: Slowly raises the weight by rotating the forearm and the wrist to a vertical position. Hold this position for 2 seconds and slowly return to the starting position (Roetert & Ellenbecker, 1998; Burkhart & Tehrany, 2002).

(a) 

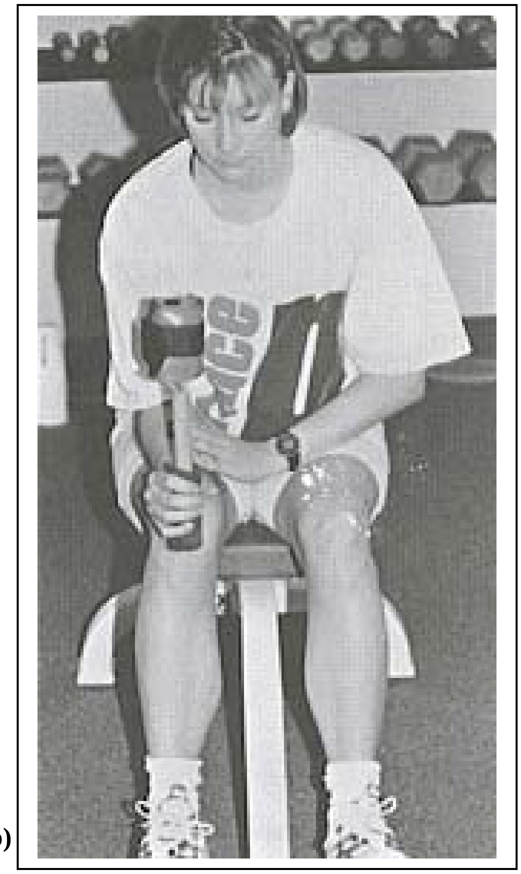
(b) 

Figure 28: Forearm supination. (a) Starting position. (b) Action (Roetert & Ellenbecker, 1998).

e. Radial deviation:

Focus: Strengthens the muscles that stabilize the wrist in tennis.

Start: Stand with the arm at the side and hold a dumbbell with a weight on only one end. The end with the weight must be in front in the neutral position with the thumb pointing straight ahead.

Action: Slowly raise the weight and then lower it through a comfortable range of motion. All the movement must be in the wrist with no elbow or shoulder joint movement (Kraemer *et al*., 1995; Roetert & Ellenbecker, 1998; Roetert, 2003).

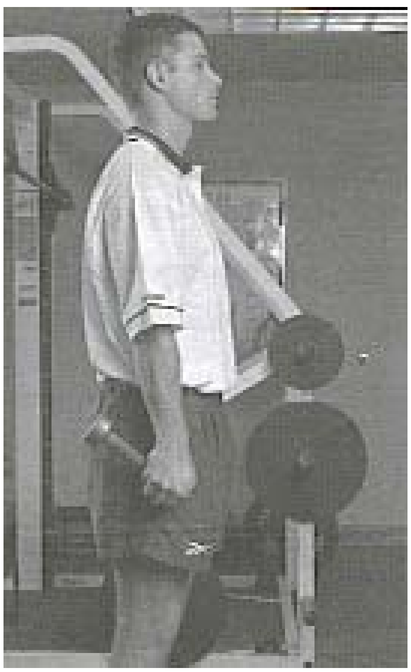
f. Ulnar deviation: (Figure 29)

Focus: Strengthens the muscles that stabilize the wrist in tennis.

Start: Stand with the arm at the side and hold a dumbbell with a weight on only one end. The end with the weight must be behind the body in the neutral position with the thumb pointing straight ahead.

Action: Slowly raise the weight and then lower it through a comfortable range of motion. All the movement must be in the wrist with no elbow or shoulder joint movement (Roetert & Ellenbecker, 1998; Burkhart & Tehrany, 2002).

(a)



(b)

Figure 29: Ulnar deviation. (a) Starting position. (b) Action (Roetert & Ellenbecker, 1998).

g. Grip strengthening:

Focus: Strengthens the forearm, wrist and the hand muscles that is used in gripping the racket in tennis.

Start: Start with the elbow bent at 90º at the side. Hold either a tennis or squash ball, or putty in the palm of the hand.

Action: Squeeze the ball or the putty as hard as possible and hold that position for three to five seconds. Release the pressure and then repeat until the hand muscles feel fatigue. Increase the intensity of this exercise by keeping the elbow straight (Kraemer *et al*., 1995; Ellenbecker *et al*., 2002).

2.7.4 Plyometric Medicine Ball Program for the Shoulders

These plyometric exercises help to develop power in the upper body (Chu, 1995). A medicine ball is used for resistance and it requires explosive movement patterns. For shoulder strengthening exercises, balls 2 to 3kg are used. In order to reduce the risk of injuries, it is recommended to start with 2kg ball and then gradually increases the load as the workout becomes easier. When you can perform more than 50 repetitions without fatigue, the weight of the ball should be increased (Kraemer *et al*., 1995; Turner & Dent, 1996).

a. Chest Pass:

Focus: Develops the pectoralis, triceps and the scapular stabilizers.

Start: Stand 5m from a partner and hold the ball in front of the chest.

Action: Pass the ball straight to the partner. The partner should try to "catch and release" the ball as quickly as possible (Turner & Dent, 1996).

b. Overhead Toss:

Focus: Strengthens the latissimus dorsi and the triceps muscles.

Start: Stand 2.5 to 3m away from a partner and hold the ball directly over the head.

Action: Toss the ball to the partner. The partner should try to "catch and release" the ball overhead as quickly as possible (Kraemer *et al*., 1995; Turner & Dent, 1996).

c. Forehand Toss:

Focus: Strengthens the muscles that are used in playing the forehand.

Start: Stand 2.5 to 3m away from a partner and hold the ball with both hands on the forehand side.

Action: Step and turn the same way as when playing a forehand taking the ball back like a racket. By mimicking a forehand crosscourt groundstroke, pass the ball to the partner. The partner must try to "catch and release" the ball as quickly as possible by performing the same forehand action (Chu, 1995; Kraemer *et al*., 1995).

d. Backhand Toss:

Focus: Strengthens the muscles that are used in playing a backhand.

Start: Stand 2.5 to 3m away from a partner and hold the ball with both hands on the backhand side.

Action: Step and turn the same way as when playing a backhand taking the ball back like a racket. By mimicking a backhand crosscourt groundstroke, pass the ball to the partner. The partner must try to "catch and release" the ball as quickly as possible by performing the same backhand action (Kraemer *et al*., 1995; Turner & Dent, 1996).

2.8 POSTURAL DEVIATIONS

Due to the early involvement in competitive sport, children are often exposed to types of stress that can affect the growth and development of their maturing musculoskeletal systems in an adverse way (Skrzek, 2003). This can lead to a disruption of the normal growth pattern. The most serious of all the growth disorders is scoliolis, due to the fact that the body may disform and then inhibit normal bodily organ function (Becker, 1986; Walker, 2003).

2.8.1 Scoliosis:

The vertebral curvature that is defined as scoliosis can be broadly categorized as *structural* or *functional* (Smith, 2003). Portillo *et al*. (1982), Willner (1984), Carlson (2003) and Smith (2003) describe *structural curvatures* as a deviation of over 10 degrees, accompanied by rotation. This definition specifies the inclusion of bone and ligament malfunction as a criterion for structural torsion that is associated with lateral curvature. Keim (1982) referred to *functional scoliosis* as a “mild” form of vertebral disorder. It is not necessary to correct this condition by an external device, but rather by side bending exercises (Katz, 2003; Milan, 2003). Tachdjian (1972), Katz (2003) and Walker (2003) noted that functional scoliosis has generally got a single long thoracolumbar curve with a predominately left convexity. Their research indicates that functional scoliosis produces little rotation of the vertebral body with accompanying rib deformity. This is a serious secondary complication of idiopathic scoliosis (Smith, 2003). A characteristic of functional sciliosis is that the curve will disappear during recumbency and suspension, and that the spine bends equally well to both sides on lateral flexion of the trunk, with rotation to both sides being equal (Becker, 1986; Skrzek, 2003; Smith, 2003).

2.8.1.1 Incidence of Scoliosis:

Idiopathic structural scoliosis is normally low among the ***normal population***, but notably higher among adolescents (Carlson, 2003; Katz, 2003). The following research shows the occurrence of scoliosis:

- ➔ Shands & Eisberg (1969) and Walker (2003) found that 1.9% or approximately 1 000 subjects out of 50 000 adolescents to have scoliosis;
- ➔ Avikainen & Vaherto (1983) and Katz (2003) reported scoliosis in 3 to 16%of the population, depending on the degree of the curvature that has been chosen as the limit, and on the age of the subject;
- ➔ Willner (1984)and Skrzek (2003) reported 0.35 to 13% as the incidence of structural scoliosis; and
- ➔ Eckerson and Axelgaard (1984) and Smith (2003) reported that ideopathic scoliosis, with a lateral curvature of unknown etiology, comprises 75 to 80% of all scoliosis in the United States.

Studies focusing on the occurrence of scoliosis among ***men and women*** showed the following:

➔ Shands and Eisberg (1969) found a predominance of scoliosis among women that is about 5 times as great as that found in the male population; and

➔ Avikainen and Vaherto (1983) reported that 90% of all cases of scoliosis, that require treatment, appear amongst women. They also found that mild scoliosis is observed to be nearly as frequent in boys as in girls.

Research on scoliosis among ***athletes*** indicates the following:

➔ Kuprian (1982) and Smith (2003) found the average frequency of ideopathic scoliosis in athletes to be 2%. He also postulated that the incidence of functional scoliosis is notable among athletes that are participating in sports that develop extreme torque in repetitive serving, throwing and volleying motions, such as tennis; and

➔ Krahl & Steinbruck (1978), Weinberg (1986) and Milan (2003) examined top athletes over 4 and 5 year intervals. They found a 33.5% incidence of functional scoliosis and a 1.6% incidence of ideopathic scoliosis .

2.8.1.2 Screening for Scoliosis:

The screening process includes observations with the athlete in the standing position and then in the forward bending position. In the erect standing position, observations should be made for asymmetries of the lateral contours of the trunk, shoulders, scapulae, and the lateral deviation of the spinal process **(Figure 30)** (Dendy *et al*., 1983; Becker, 1986; Smith, 2003; Walker, 2003).

(a) (b)

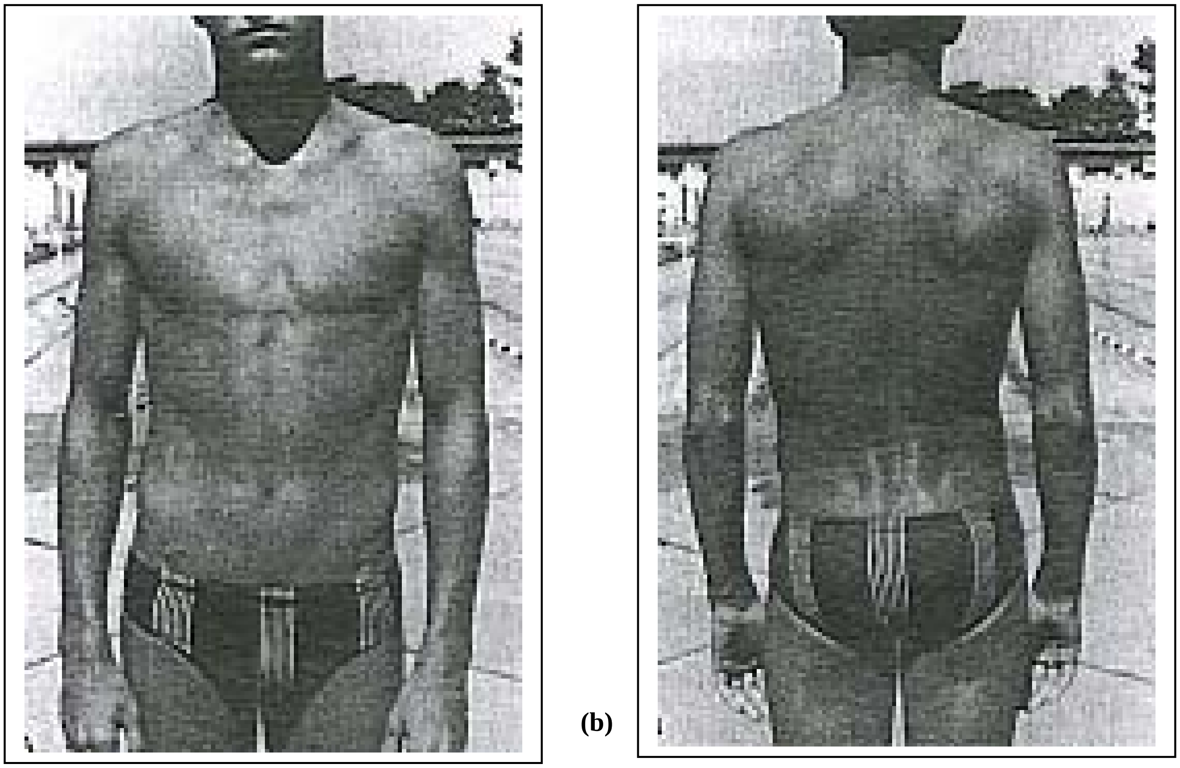


Figure 30: (a) and (b): Athletes screened for scoliosis were observed in the standing position for asymmetries of the lateral contours of the trunk, shoulders and the scapula.

In the forward bending position, the *observed rib hump* asymmetry is considered to be the positive clinical finding for structural idiopathic scoliosis (Katz, 2003).

2.8.1.3 Development of the Scoliotic Curvature:

Hauser (1937), Carlson (2003) and Skrzek (2003) found that an inability of the musculature of the back to perform up to the requirements of the demand would ordinarily produce an increase in all the normal curves of the spine. This attributes to the functional adaptation of the spine, with a subsequent muscular imbalance between the anterior and posterior structures, which is recognized as ‘poor posture’ (Katz, 2003). They also reported that if this imbalance is not corrected, a lateral curve might develop, producing a compensatory structural scoliotic development (Carlson, 2003; Skrzek, 2003). Carlson (2003) and Skrzek (2003) concluded that whenever there is a decrease in the strength of the structure of the back, a loss of capacity, or an increase on the demand made on the back, such as overload, scoliosis would develop. Krahl and Steinbruck (1978) and Milan (2003) noted that unilateral upper limb motion in athletes is a torsional repetitive motion. This motion occurs in combination with trunk rotation. Becker (1986) found a 100% occurrence of lateral curvature to the side of the dominant hand. This supports the effect of muscular imbalance as noted by Katz (2003) and Smith (2003) and the dominant arm strength as noted by Yeater *et al*. (1981), Milan (2003) and Skrzek (2003).