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# BIOMECHANICAL OVERLOAD OF THE WRIST IN MILKING PARLOR WORKERS: RISK PROFILES AND POSSIBLE PREVENTION CRITERIA


BY
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To my lovely family :
my dad Elio, my mum  Antonella, my grandma Elvira, my sisters Valentina and Ilenia, my brothers in law Antonio and Federico, my sweet niece Francesco and  the good star always looking at me from the heaven, my grandma Marietta.
Always supporting my goals and my dreams

*Working for those who work and not least for those who would like to, but cannot (Pope Francis)*

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# Contents

## ABSTRACT

The association between biomechanical risks and musculoskeletal disorders in agriculture is evident, but data on dairy sector are scarce. This project, addressed at fulfilling some of the knowledge gaps and at creating exposure and risk profiles for specific milking parlor activities, has been conducted in order to:

a) estimating the effects on wrists of parlors' workers of repetitive motions, pointing out an ultrasonography approach;
b) developing screening tools useful in the periodical health surveillance of dairy workers to detect early wrists' changes;
c) Compare the levels of muscle activation in milking work between large herd and small herd operations.
d) define preventive criteria addressed at risk control in dairy activities;

The project has been carried out in 4 single studies, In the first, 14 parlor workers and 22 controls were studied through a) personal anamnesis collection; b) wrists ultrasonography; c) upper limb clinical evaluation. The study confirmed the wrist as target of biomechanical risk factors and identified the two wrist's acoustic window characterized by the highest predictive value for wrist's structure alteration. The **second study** has been conducted on 40 dairy workers, studied with the approach defined in the first study. Main objective has been evaluating the levels of concordance between questionnaire results and clinical and ultrasound evidences. The questionnaire showed a high level of specificity (82.15%. C.I.95%: 62.4%-93.2%) and sensitivity (45,45%. C.I. 95%: 18.1%-75.4%) if compared with clinical investigation outcomes and/or ultrasound findings. The study allowed to conclude that 1) the administration of a questionnaire can be predictive of early wrist's changes. 2) The questionnaire created is adequate for the periodical screening of parlor workers' wrist. The same population was involved in the **third study,** addressed to defining risk profiles of wrist biomechanical overload of parlor workers. Anthropometric measurements, personal

and occupational variables, surface electromyography data of brachial muscles were collected to define activation profiles. Strain Index for each single milking subtask (pre dipping, wiping/stripping, attaching, post dipping) has been evaluated. The study defined three main risk profiles: low, medium and high risk. Main risk determinants were: characteristics of the workstation, organization of the work, milking routine. We concluded that organization of the milking routine, and cluster weight not major than 2.4 Kg are useful interventions to be carried out. The **fourth study** was conducted to compare upper limb muscle activity between US and Italian industrialized Dairy operations. Twenty-nine workers were recruited from large herd US (Colorado) dairies and 39 from small herd Italian dairies. Surface electromyography was used to assess muscle exertion levels of all workers, measuring intensity, expressed as root mean square of the raw signal, amplitude probability distribution function percentiles, and the percent muscular rest of the interested muscles. The statistical analyses indicated significantly greater average muscle activity during milking tasks among large herd versus small herd dairy workers in the biceps brachii ($p<0.001$), upper trapezius ($p=0.002$), and the wrist flexors ($p<0.001$) between the two dairy types. This study also demonstrated that, independently from the size and the country, parlor activities pose significant biomechanical wrist risk.

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# 1. Introduction

Musculoskeletal disorders (MSDs) were recognized as having occupational etiologic factors as early as the beginning of the 18th century. In fact, they were described by Bernardino Ramazzini, an Italian physician and father of occupational medicine when he said the diseases: “arise from three causes: first constant sitting, the perpetual motion of the hand in the same manner, and thirdly the attention and the application of the mind.”[1]

However, it was not until the 1970's that occupational factors were examined using epidemiologic methods, and the work-relatedness of these conditions began appearing regularly in the international scientific literature. Since then the literature has increased dramatically. Yet, the relationship between MSDs and work-related factors remains the subject of considerable debate. [2]

The World Health Organization has characterized “work-related” diseases as multifactorial to indicate that a number of risk factors (e.g., physical, work organizational, psychosocial, individual, and sociocultural) contribute to causing these diseases. [3]

MSDs involves muscles, nerves, tendons, joints, cartilage, and spinalcolumn, covering a wide range of health problems. The main groups are back pain and injuries, and Work Related Upper Limb Disorders (ULDs) that affect the arms, from fingers to shoulder and neck. WMSDs are very difficult to define within traditional disease classifications and during the past years have received many names [4], such as repetitive motion injuries; repetitive strain injuries; cumulative trauma disorders; occupational cervicobrachial disorders; overuse syndrome; regional musculoskeletal disorders; soft tissue disorders. Recent studies still provide substantial evidence that MSDs are a significant ill health and cost problem and are increasing. They impact on employees' work ability not only at the individual perspective but also at national one [5,6,], affecting efficiency, productivity and quality in every organization and labor market [7]. Millions of European workers across all employment sectors are affected by those disorders at a cost of billions of Euros to employers. According to 2010 Osha survey, 45% of European workers report working in painful or tiring positions, 33% are required to handle heavy loads in their work. Workers have reported to be in pain: 30% complain of backache (44 million European), 17% complain of muscular pains in their arms. [8]

Beyond different recognition practices, there are indications that MSD are affecting the female working population more than the male one and that the age of onset is increasingly early. Certain studies estimate  that in Europe the social costs of MSD range between 0.5 and 2.0 per cent of Gross National Product [8, 9]. Same situation in USA, were MSD have an economic burden that affects employers with medical costs totaling nearly $20 billion annually [4] since over 600,000 injuries and illnesses (34% of all lost workdays reported to the Bureau of Labor Statistics). Thereby work in safe and ergonomically favorable conditions, creating qualitative work places is also an economic necessity [10].

One important reason for the debate surrounding work-related MSDs is their multifactorial nature. As for other sectors, even in agriculture epidemiologic studies aims at identifying factors positively or negatively associated with the development or recurrence of adverse medical conditions.

## 1.1 The wrist-hand district

### 1.1.1 Wrist joint anatomy

The wrist is a complex joint that bridges the hand to the forearm composed by multiple bones and joints. Human wrist includes eight carpal bones, which are arranged in two rows [11]. The carpal bones connect proximally to the radius of the forearm and distally to the five metacarpals of the hand [12]. (**Figures 1, 2**).

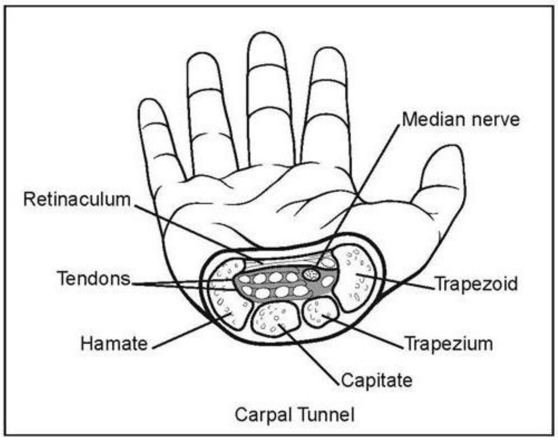


**Figure 1** Wrist, palmar view

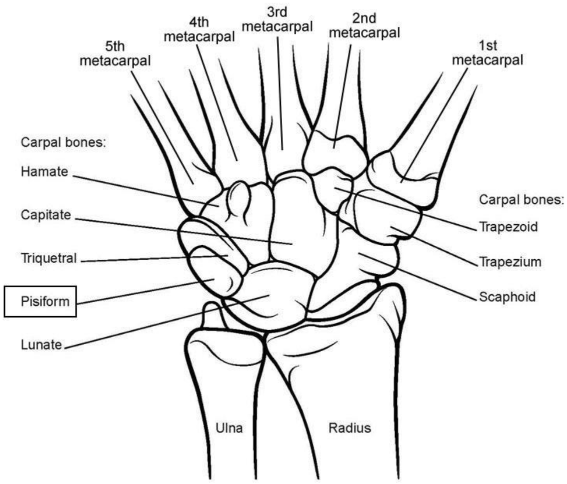


**Figure 2** Bones of the wrist, enlarged view.

All of these bones participate in complex articulations that allow variable mobility of the hand. Humans use their hands for tasks which have a high degree of complexity and utility. The wrist's role is critical in most functional operations of the human hand. [13]

The International Society of Biomechanics (ISB) has defined anatomical terms of movements [14]. Relative to the forearm, the hand is capable of 3 degrees of freedom: pronating and supinating (**figures 3a - 3b**), flexing and extending (**figure 4a- 4b**), and deviating ulnarly or radially (**figure 5a - 5b**). [15,16,17,18,19]

The **pronation-supination** movements happen when the human wrist rotates, while the palm's direction changes with no variation in the palm-to-arm or thumb-to-arm angles [20]. For the right hand, the counterclockwise motion is defined as pronation, and the clockwise motion is called supination. In pronation, the position of the palm changes from facing sideways to facing down [13]. The range of maximum motion for pronation and supination together is 125˚, with 60% of this range allocated to pronation [21].

The vertical movements of the human wrist are called **flexion-extension**. The vertical movement of the wrist when it moves upward is called extension and the downward vertical movement is called flexion. In the extension-flexion movements the angle between the palm of the hand and the arm changes. The maximum rotation for flexion is 60˚ and for extension is equal to 45˚ [22].

The horizontal tilt of the wrist makes the thumb-arm angle change. This movement is called radial when hand rotates to the thumb side and ulnar when the hand rotates to the opposite side [10]. Figure (5a) and (5b) shows the **radial-ulnar movements**.

For radial and ulnar movements the range of rotation is 30˚ and 15˚, respectively [21].

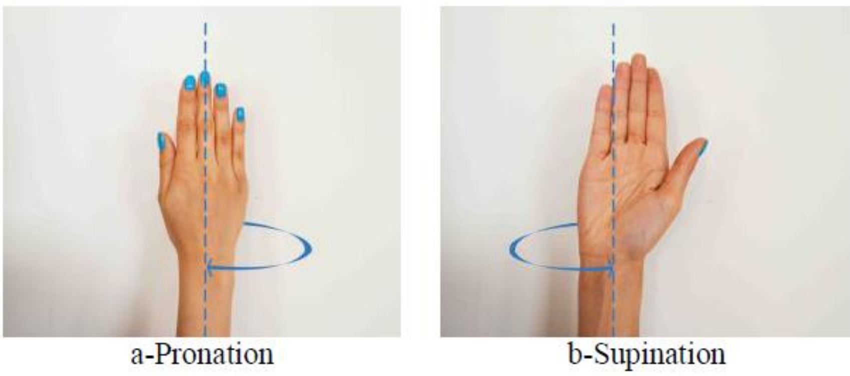
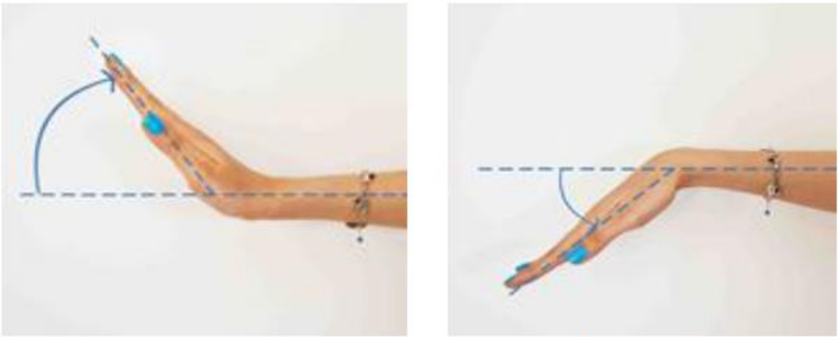
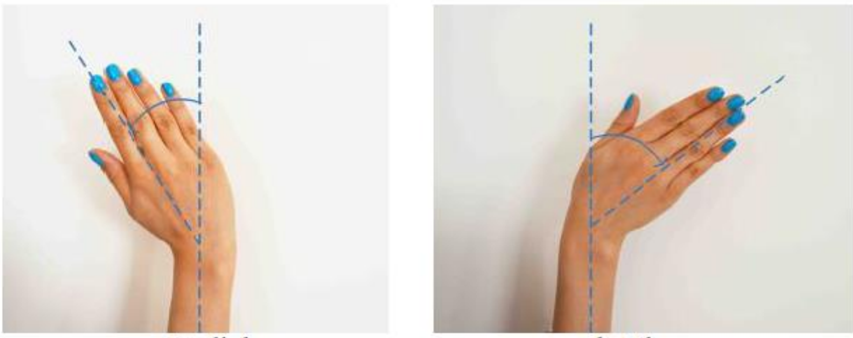



**Figure 3** Wrist's Pronation – Supination movements



a-Extension b-Flexion

**Figure 4** Wrist's Extension- Flexion movements



a-Radial b-Ulnar

**Figure 5** Wrist's Ulnar – Radial movements

As shown in the following images (**Figure 6 and 7**), the wrist joint has a complex configuration of ligaments that guarantee the mobility of the wrist, without sacrificing stability.

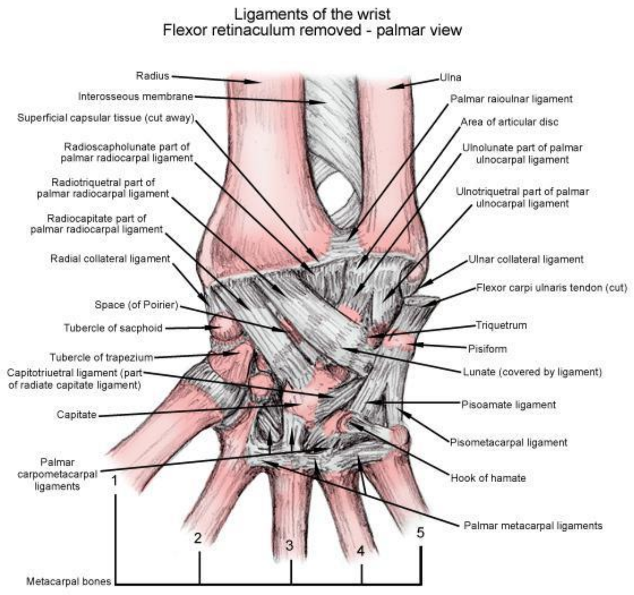



**Figure 6** Ligaments of the wrist, palmar view.

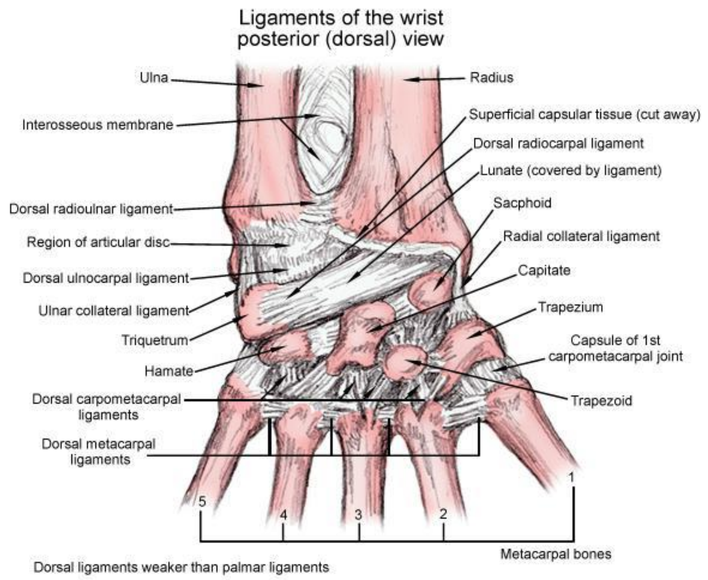



**Figure 7** Ligaments of the wrist, posterior (dorsal) view.

The anatomic linkage between the distal forearm and the hand is composed of 15 bones: 8 carpal bones, the distal radius and ulnar, and the bases of the 5 metacarpals.

## Carpal bones

The carpal bones are organized into 2 groups, a proximal row and a distal row. The proximal row is found at the level of the distal wrist crease and includes the scaphoid, lunate, triquetrum, and pisiform. The second row of carpal bones, the distal row, is made up of the trapezium, trapezoid, capitate, and hamate; the distal row articulates with the bases of the 5 metacarpal bones. The proximal carpal row bones represent an intercalated segment, as no tendons insert upon them [23]. Therefore, their movement is dependent entirely on mechanical forces from surrounding articulations.

The bones of the distal row are closely adherent to each other via intercarpal ligaments (see the images below). These bones are also tightly bound to the metacarpal bones, representing the carpometacarpal (CMC) joint. In particular, the ligamentous connection between the trapezoid and capitate to the index (second) and middle (third) finger metacarpals, respectively, are so rigid that the distal carpal row has been considered a component of a fixed hand unit that moves in response to musculotendinous forces generated from the forearm. [24]

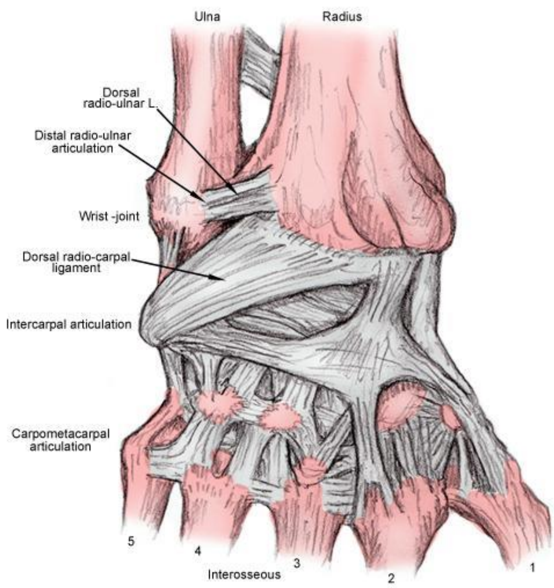



**Figure 8** Volar carpal ligaments.

The joints of the wrist are surrounded by a fibrous capsule and are held together by an array of ligaments that provide carpal stability by linking the bones both dorsally and volarly (**figure 8**). These carpal ligaments are divided into 2 groups: intrinsic ligaments that originate and insert on carpal bones and extrinsic ligaments that bridge carpal bones to the radius or metacarpals. [25] Extrinsic ligaments volar are: *Radioscaphocapitate ligament, Long radiolunate ligament, Short radiolunate ligament, Radioscapholunate ligament, Ulnolunate ligament, Ulnocapitate ligament.*(**Figure 9**)

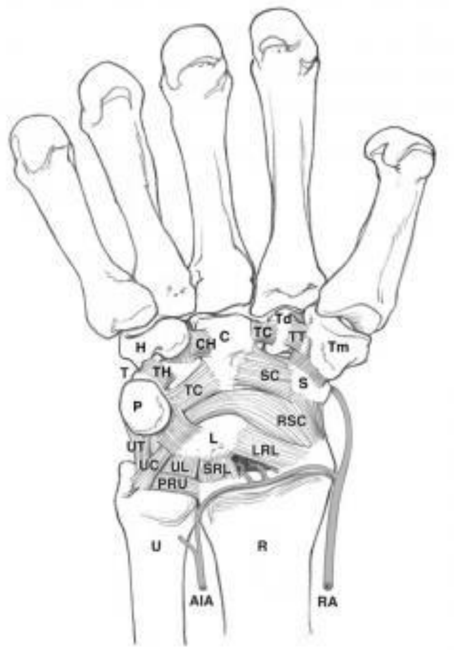



**Figure 9** Volar carpal ligaments and bones

AIA = anterior interosseous artery; C = capitate; CH = capitohamate; H = hamate; L= lunate; LRL = long radiolunate ligament; P = pisiform; PRU = palmar radioulnar ligament; R = radius; RA = radial artery; RSC = radioscapholunate ligament; S = scaphoid; SC = scaphocapitate ligament; SRL = short radiolunate ligament; T = triquetrum; TC = triquetrocapitate ligament; Td = trapezoid; TH = triquetrohamate ligament; Tm = trapezium; TT = trapeziotrapezoid ligament; U = ulna; UC = ulnocarpal ligament; UL = ulnolunate ligament; UT = ulnotriquetral ligament.

Extrinsic ligaments, dorsal are: ***Intercarpal ligaments, Radiocarpal ligament***

Intrinsic ligaments, volar are: ***Lunotriquetral ligament, Trapeziotrapezoid ligament,*** *Scaphotrapezial ligament*, *Scaphotrapezoidal ligament*, *Scaphocapitate ligament*, *Capitotrapezoid ligament*, *Capitohamate ligament*, *Triquetrocapitate ligament*, *Triquetrohamate ligament.*

The fourth metacarpal base has 5 distinct shapes, categorized as types I-V, as follows:

- Type I: Broad base with articulation with the hamate and one dorsal facet that is in contact with the capitate
- Type II: Broad base with articulation with the hamate and 2 facets (dorsal and volar) that articulate with the capitate
- Type III: Narrow base that solely articulates with the hamate
- Type IV: Broad base that articulates with the hamate

**Intrinsic ligaments, dorsal** are: *Intercarpal ligament*, *Trapeziotrapezoid ligament*, *Capitotrapezoid ligament, Capitohamate ligament, Triquetrohamate ligament*

**Interosseous ligaments** are: *Scapholunate ligament*, *Lunotriquetral ligament*, *Trapeziotrapezoid ligament, Capitotrapezoid ligament, Capitohamate ligament*.

**Natural Variants**

Research over the past few decades has increased our understanding of the normal anatomic variants germane to the hand and wrist. Without this working knowledge, variations in skeletal morphology may be misinterpreted as being clinically abnormal and lead to misdiagnosis and inappropriate intervention.(http://emedicine.medscape.com/article/1899456-overview)

**Carpometacarpal joint**

- One variation is related to the carpometacarpal joint, more specifically the shape of the fourth metacarpal base. Studies have revealed that the most common variation in the carpometacarpal joint exists at the fourth carpnd a single, separate facet that articulates with the capitate
- Type V: Relatively broad base without any projections or separate articular surface articulates with the hamate and the capitate

**Midcarpal joint**

In regards of the midcarpal joint, 2 areas of variability have been founded. The first is in relation to the lunate bone, in particular its onset of ossification and shape. Double ossification centers, as well as complete absence of the lunate, have been identified. Two types of lunates have been reported: Type I lacks a medial facet, whereas type II has a medial facet that articulates with the hamate [12].

Variability has been identified within the midcarpal joint, at the distal articulation of the scaphoid. Three variations have been described: (1) separate facets for articulation with the trapezoid and trapezium, with an interfacet ridge separating the facets; (2) separate trapezoid and trapezium facets with palpable interfacet ridge, not visually identifiable; and (3) smooth articular surface not visually identifiable.

The isolated carpal coalition is an anatomic variant with a prevalence of 0.1%. This finding is more common in the black population, commonly bilateral, and has a strong female predilection. The lunotriquetral, followed by the capitohamate, are the most common carpal coalitions. Of note, persons with lunotriquetral coalition may have a widened scapholunate joint, representing a normal variant. (http://emedicine.medscape.com/article/1899456-overview)

### 1.1.2 The principal occupational wrist-hand musculoskeletal disorders and their diagnosis

Some pain syndromes affecting the hands are usually associated with exposure to occupational factors. Since hand function plays an essential role in carrying out activities of daily living, hand syndromes pose a relevant burden of disease and therefore are a priority for prevention.

The most frequent hand pain syndromes are carpal tunnel syndrome (CTS), flexor and extensor tenosynovitis of the wrist and in particular De Quervain's tenosynovitis (DQT), tendinosis. The strength of the association between a specific syndrome and the putative pathogenic occupational factor is variable depending on the condition and the characteristics of the activity implicated [26]

Unfortunately, disagreement exists about case definition of MSD and about the distinction, relation and overlap between conditions. The variety of criteria used in research and this lack of consensus hampers comparability across studies. [27, 28, 29] Since that, seems critical to obtain accurate data on incidence, prevalence, outcome and response to treatment, both in general population and in individuals exposed to risk factor at workplace. Self-administered questionnaires and surveys have been extensively used in the identification of work-related MSDs. But it is not clear how self-reports of pain are related to physicians' diagnoses and physical signs obtained during a structured examination, and how both of them could be best employed to define MSD cases in epidemiologic studies. [26]

In order to address the issue of case definition in upper-limb disorders, a workshop, convened by the United Kingdom Health and Safety Executive, developed consensus criteria for some of the most common upper-limb disorders using a Delphi technique (**Table 1**). [29]

| *Disorders* | *Diagnostic Criteria* |
|---|---|
| **De Quervain's disease of the wrist** | Pain over the radial styloid and tender swelling of the first extensor compartment and either pain reproduced by resisted extension or positive Finkelstein's test |
| **Tenosynovitis of wrist** | Pain on movement localized to the tendon sheaths in the wrist and reproduction of pain by resisted active movement |
| **Carpal Tunnel Syndrome (CTS)** | Pain or paresthesia os sensory loss in the median nerve distribution abd one of the following items:<br>Positive Tinel's test<br>Positive Phalen's Test<br>Nocturnal exacerbation of the symptoms<br>Motor loss with wasting of abductor pollicis brevis muscle<br>Abnormal nerve conduction time |

**Table 1** Diagnostic criteria for occupational related hand disorders*

*adapted from Palmer et Al., 2000 [30]

Regarding hand pain syndromes, criteria by Harrington et al. defined CTS, DQT and wrist tenosynovitis [31].

#### *1.1.2.1 Carpal Tunnel Syndrome*

Carpal tunnel syndrome (CTS) is a common peripheral entrapment neuropathy resulting from compression of the median nerve at the wrist that often results in high medical treatment costs, lost work time and associated disability [32]. Studies on CTS have reviewed the potential risk factors and confirmed its relationship with biomechanical exposure at work [2,34,35,36,37,38,29,40,41,42,43,44,45,46,47,48,49,50].

There is clear evidence that among the main occupational risk factors for CTS repetition, force and posture are prominent. Furthermore, the important interaction between force and repetition on MSDs has been even [51] documented at the tissue level [52,53] and in epidemiological studies of working populations [34, 55].

The diagnosis is reached through the evidence of median nerve symptoms and exposure to one or more occupational risk factors. Classical form of CTS is readily diagnosed on history and examination alone. Nerve conduction testing is generally regarded as the gold standard for the diagnosis of CTS. A short summary of the diagnostic approaches:

**Physical examination:** Objective weakness occurs in advanced CTS in muscles of the thenar eminence which manifests mainly as weakness of thumb abduction and thumb opposition.

- Personal characteristics: age, gender, weight, height, body habitus, etc.
- Positive Flick Sign
- Range of motion of hand/wrist
- Observation of deformity, swelling, atrophy, skin trophic changes
- Pinch/grip strength
- Hand diagram
- Sensory examination: e.g., two-point discrimination, Semmes-Weinstein monofilament, vibrometry, texture discrimination, etc.
- Manual muscle testing: of the upper extremity (e.g., examine for muscular atrophy, especially thenar muscle group)
- Provocative tests: (e.g., Phalen’s test, Tinel’s sign, median nerve compression test, reverse Phalen’s, etc.)
- Discriminatory examination for alternative diagnoses: e.g., radiculopathy, neuropathy, pain syndromes, arthritis, tendonitis, vascular abnormalities, etc.

Pathognomonic symptoms include numbness, tingling, or burning pain in the volar aspects of one or both hands, usually observed after work or during the night.

Nocturnal symptoms are prominent in 50-70% of patients. Patients frequently awaken at night or early morning and shake their hands to relieve these symptoms. The location of these symptoms may be reported as involving the entire hand or localized to the thumb and first two or three fingers. If the nerve symptoms are prominent only in the fourth and fifth fingers, a different diagnosis (e.g.

ulnar neuropathy or C-8 radiculopathy) should be considered. Although burning pain is often prominent in the hands and palm side of the wrists, an aching pain may radiate to the medial elbow region or more proximally to the shoulder. Proximal symptoms, especially tingling in the radial hand combined with lateral elbow pain should raise questions about a possible C-6 radiculopathy. Findings on physical examination, signs, are frequently absent or non-specific. Hoffmann-Tinel's sign (paresthesias radiating in a median nerve distribution with tapping on the wrist or over the median nerve) and Phalen's sign (paresthesias radiating in a median nerve distribution within 60 seconds of sustained flexion of the wrist) are frequently described, but by themselves are not sensitive or specific for the diagnosis of CTS. Their presence may corroborate the presence of other clear neurologic symptoms. Likewise, non-specific symptoms, (e.g., pain without numbness, tingling or burning; "dropping things") by themselves are not diagnostic of CTS. [56]

**Paraclinical tests:** CTS represents a clinical diagnosis that can be confirmed with diagnostic testing (Nerve conduction studies).

- Electrodiagnostic tests: they may help in differential diagnoses. They are recommended in particular in the presence of thenar atropy and/or persistent numbness and if clinical and/or provocative tests are positive and surgical management is being considered. Sensory conduction of the median nerve should be compared with the ulnar and radial nerves, since it results impaired in most patients. Needle EMG at the discretion of the physician.

Recent articles seems to confirm that sonography using cross-sectional area of the median nerve could give complementary results. Some others have suggested that Magnetic Resonance Imaging (MRI) neurography and ultrasound may have utility in the diagnosis of CTS. However, these tests have not been shown to be more accurate than EDX in high quality studies. [57, 58]

**Differential diagnosis**

- Other conditions may present with symptoms similar to those found in carpal tunnel syndrome (e.g., cervical radiculopathy, hypothyroidism, peripheral neuropathy, wrist/trapeziometacarpal arthrosis, wrist tendonitis/tenosynovitis, Raynaud's, arterial injury or thrombosis, nerve laceration, neuroma, brachial plexus injury, other nerve entrapment syndromes, pain syndromes, etc.). Physical examination should include other areas of the upper extremity and neck that may relate to these alternative diagnoses. This may include the following:
    - Muscular atrophy or weakness of the shoulder, elbow, wrist, thumb and/or fingers.
    - Active range of motion, particularly for the wrist and digits.
    - Swelling, masses and/or tenderness around the wrist or digits.
    - Capillary refill, radial and ulnar pulses, Allen's test.
    - Wounds or scars on the upper extremity.
    - Cervical spine range of motion, Spurling's sign.
    - Thyroid enlargement.

### *1.1.2.2 Tenosynovitis*

The term "Tenosynovitis" defines an inflammation of a tendon surrounded by a synovial sheath. If the sheath becomes inflamed and gradually compress the tendon, occluding the canal, it is called stenosing tenosynovitis. Diagnostic criteria of wrist tenosynovitis were defined as pain on movement localized to the tendon sheaths in the wrist and reproduction of pain by resisted active movement [23]. In particular **De Quervain (DQT**) it is a particular form, which affects the thumb.

DQT is a stenosing tenosynovitis that involves the extrinsic extensors of the thumb carpometacarpal and metacarpophalangeal joints. The abductor pollicis longus and the extensor pollicis brevis muscles are connected to the thumb by tendons that pass through fibrous tendon sheaths along the radial aspect of the wrist. Just as in stenosing flexor tenosynovitis of the fingers, volume discrepancies due to inflammation may cause stenosis of the first dorsal compartment and result in impingement of the smooth gliding of abductor pollicis longus and extensor pollicis brevis tendons within the first dorsal compartment. [30].

The diagnosis of De Quervain tenosynovitis can be made based on personal, medical and occupational history and physical examination. A positive finding on ***Finkelstein's test*** is considered the gold standard.

Additional criteria are hand, wrist, or forearm radiographs within 6 months of clinical diagnosis.

**Typical clinical signs and symptoms:**

- Intermittent pain or tenderness localized over the radial side of the wrist; either may radiate proximally to the forearm or distally to the thumb. Palpation tenderness and in some cases thickening on palpation at the constriction site (tender swelling of the first extensor compartment), sometimes-nodular thickening is visible, can be observed. Other typical symptoms are pain over the radial styloid and after resisted thumb extension, together with abduction or positive Finkelstein's test on examination.
- Bending the wrist towards the little finger with the thumb flexed in the palm (Finkelstein's test) typically exacerbates the symptoms. Some cases show triggering or snapping upon moving the thumb.
- The onset is usually observed during exposure, or at least 4 days during the last 7 days, or at least 4 days during at least 1 week in the last 12 months.
- The pathological changes include thickened outer layers of the tendon sheaths. The tendon may be constricted and show enlargement beyond the site of constriction.

History confirms an association with work activities involving prolonged repetitive movements, forceful exertions and extreme postures of the wrist.

**Paraclinical tests:**

- Sonographic and MR imaging findings of de Quervain tenosynovitis have been described, as consisting of tendon sheath thickening non necessarily but often accompanied by soft-tissue edema.
- Focal radial styloid abnormality (cortical erosion, sclerosis, and periosteal bone apposition) is an indicator of de Quervain stenosing tenosynovitis of the wrist.

**Differential diagnosis:**

- Osteoarthritis.
- Wartenberg's syndrome.
- Intersection syndrome.
- Wrist sprains.

### *1.1.2.3 Tendinitis*

**Tendinitis** is inflammation of a tendon, often associated with compression / tension repeated. The painful symptoms specific guides on diagnosis, it helps with the pressure test (TA, ON, SR), and the ultrasound examination can put very well highlighted the morphological alterations: thickening, surface irregularities, fragmentation and calcification.

There is evidence of an association between any single factor (repetition, force, and posture) and hand/wrist tendinitis, based on currently available epidemiologic data. There is strong evidence that job tasks that require a combination of risk factors (e.g., highly repetitious, forceful hand/wrist exertions) increase risk for hand/wrist tendinitis. [2]

The estimated prevalence for common upper extremity MSDs (shoulder tendinosis, lateral epicondylalgia, and CTS) vary widely depending on the epidemiological case definition used. Recent studies resulted differences in prevalence of three of the most common upper-extremity MSDs. It remains to be determined whether these large variations in prevalence have impacts on purported risk factors. Differences in epidemiological case definitions used may explain some of the discrepancies in the results. [26]

Most of the available studies on workers' wrist and nerves have been conducted with ultrasound examination, which seems to be highly sensitive for detecting abnormalities, but unable to provide information regarding the severity of the changes[59]. For this reason, ultrasound approach must be accompanied by physical examination and symptom collection [60].

### 1.1.3 Epidemiology of wrist-hand disorders

Accurate data on the incidence and prevalence of WRMSD are difficult to obtain, and official statistics are difficult to compare across countries. Nevertheless, MSDs are the single largest category of work-related illness, representing a third or more of all registered occupational diseases in the United States, the Nordic countries, and Japan [61, 62, 63]. In the United States, Canada, Finland, Sweden, and England, musculoskeletal disorders cause more work absenteeism or disability than any other group of diseases [64,65,66,67, 68]. Numerous peerreviewed authors have concurred that the epidemiologic evidence demonstrates the etiologic importance of occupational ergonomic stressors for MSDs of the low back and upper extremity [69, 70, 71, 72, 73,74, 75]

In 2005, according to the European Occupational Disease Statistics(EODS, Eurostat accessed December 2015) obligatory list the proportion of musculoskeletal disorders was about 38% of the total occupational diseases (**Figure 10**). Carpal tunnel syndrome (99% of the neurologic diseases), a neurological disease of the wrist, is normally added to the figures.

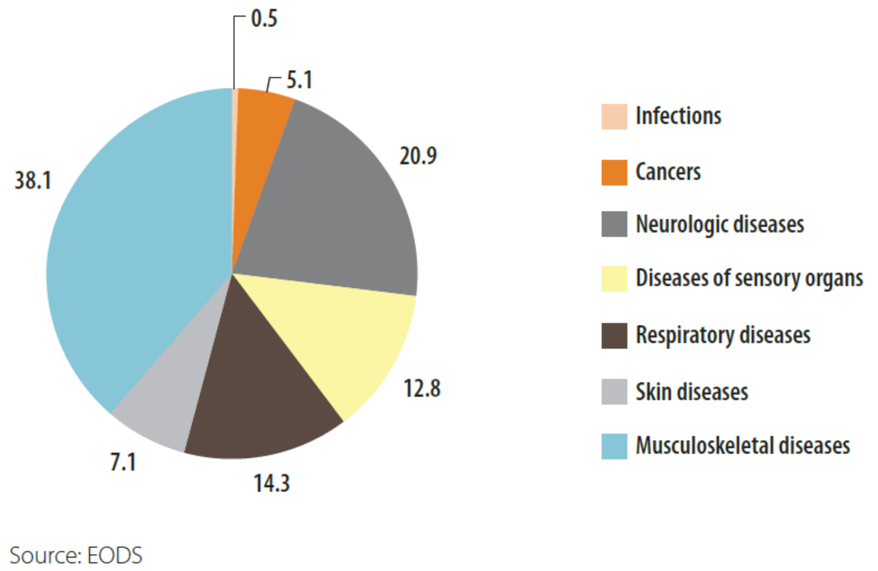



**Figure 10** Incidence of different occupational diseases in Europe, EODS obligatory list, 2005

The most common musculoskeletal occupational diseases are tenosynovitis of the hand or wrist, and epicondylitis of the elbow. (**Table 2** ).

| | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|
| Carpal tunnel (g560) | 2,483 | 12,575 | 14,058 | 14,964 | 17,395 |
| Musculoskeletal diseases (m00_to_m99) | 11,189 | 24,696 | 26,601 | 28,734 | 31,658 |
| Arthrosis of the elbow (m192) | 12 | 88 | 90 | 87 | 81 |
| Meniscal lesions (m232) | 334 | 693 | 694 | 751 | 672 |
| Hand or wrist tenosynovitis (m700) | 5,379 | 10,028 | 11,246 | 11,629 | 12,962 |
| Bursitis of elbow (m703) | 183 | 380 | 338 | 340 | 485 |
| Bursitis of knee (m704) | 442 | 1,337 | 1,269 | 1,347 | 1,290 |
| Medial epicondylitis (m770) | 428 | 1,130 | 1,400 | 1,670 | 1,899 |
| Lateral epicondylitis (m771) | 4,157 | 10,658 | 11,494 | 12,840 | 14,155 |
| Arthrosis of the wrist (m931) | 254 | 382 | 70 | 70 | 114 |

Source: EODS

**Table 2** Number of occupational diseases, EODS obligatory list, 2001-2005

In 1999 the Labour Force Survey (LFS) - Work-related health problems and occupational accidents Module [76] reported the highest incidence rates of MSDs among workers in health and Social work, transport, storage and communication, construction and agriculture (1.2 to 1.6 times higher than average). (**figure 11**)

According to European Survey on Working Conditions (ESWC), on the other hand, in 2005, about 35.4% of European workers considered that their work affects their health. 24.7% of them reported suffering from backache, a share that is doubled among workers in agriculture and fishing (50.5%), and higher in construction (36.5%) and transport, storage and communication (28.4%), followed by health and social work (26.3%). Same situation is reported for muscular pain (**figure 12**). [76]

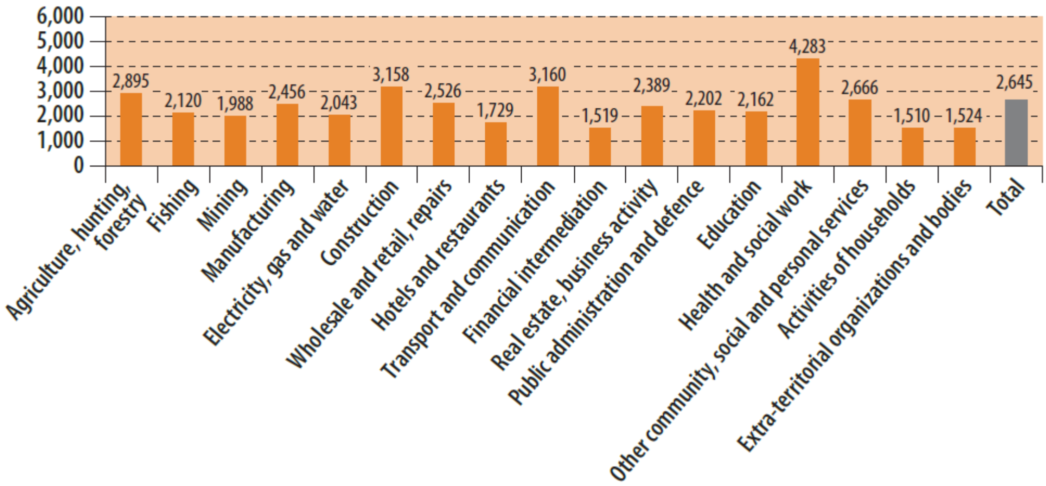
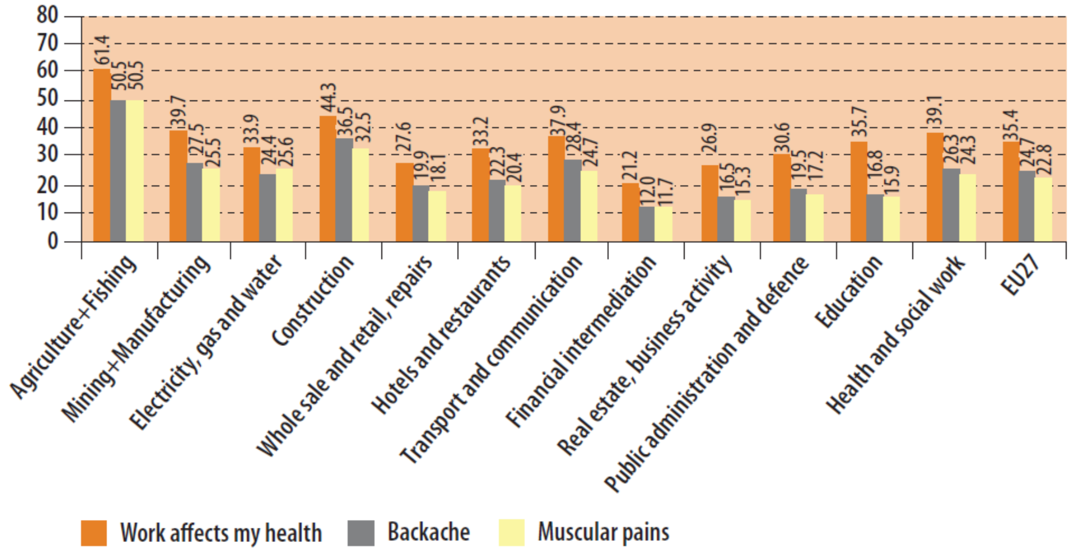



**Figure 11** Standardized prevalence rate (per 100,000 workers) of musculoskeletal disorders, by sector, ad hoc module LFS 1999




Source: ESWC

**Figure 12** Percentage share of workers reporting health problems, backache and muscular pains, by sector, EU27, 2005

In **Italy**, the total number of cases occupational muscle skeletal diseases in the agriculture sector reported in 2007 to the Italian Workers compensation authority (INAIL) was 923, in 2011 this figure has increased by 613.4%, reaching the number of 6585 (**table 3**) [77]. This significant increase is due to two main factors: the first is the inclusion of musculoskeletal disorders among those to be mandatory notified to the Workers Compensation Authority, and in the list of diseases eligible for compensation; the second is the increased awareness about the concept of "health", not as the mere absence of disease but as the welfare of the individual in all its potential, finally the increased health surveillance coverage.

| Occupational diseases | 2007 | 2008 | 2009 | 2010 | 2011 | Var % 2007-2011 |
|---|---|---|---|---|---|---|
| **MSDs** | **923** | **1109** | **2859** | **5156** | **6585** | **+613,3** |
| **Hearing loss** | **277** | **265** | **359** | **565** | **615** | **+122** |
| Respiratory diseases | **154** | **156** | **215** | **240** | **254** | **+64,9** |
| Cancer | **32** | **23** | **34** | **58** | **64** | **+100** |
| Skin diseases | **25** | **33** | **43** | **43** | **32** | **+28** |
| Total | **1650** | **1832** | **3926** | **6389** | **7971** | **+613,4** |

**Table 3** Occupational diseases in agriculture. 2007-2011 SOURCE: INAIL

Even if a small decrease has been registered during the last four years, the Italian workers' compensation Authority still reports very high number of MSDs cases (3452).

Explanation; immediately after enforcement of legislation or interventions, the trend ODs reports increases (it is due to the report of unreported diseases). After that, it tends to go down, non being and high number of new diseases.

| Occupational Diseases (ICD- 10) | Notification Years | | | | |
|---|---|---|---|---|---|
| | 2010 | 2011 | 2012 | 2013 | 2014 |
| Infective and parasitic diseases | 0 | 1 | 0 | 1 | 1 |
| tumors | 17 | 30 | 33 | 31 | 49 |
| Mental and behavioral disorders | 0 | 0 | 0 | 1 | 0 |
| Diseases of the nervous system | 730 | 941 | 852 | 959 | 933 |
| Eye diseases | 3 | 1 | 0 | 1 | 1 |
| ear diseases | 232 | 255 | 208 | 287 | 244 |
| Diseases of the circulatory system | 16 | 6 | 1 | 6 | 3 |
| Diseases of the respiratory system | 72 | 69 | 41 | 59 | 51 |
| Digestive diseases | 0 | 1 | 1 | 0 | 0 |
| Skin diseases | 10 | 15 | 11 | 14 | 16 |
| MSD | 2030 | 2659 | 2792 | 3394 | 3452 |
| Trauma, poisoning or other | 0 | 0 | 1 | 0 | 0 |
| not determined | 10 | 0 | 3 | 3 | 14 |
| total | 3120 | 3978 | 3943 | 4756 | 4764 |

**Table 4.** Agriculture - Occupational Diseases defined per Characteristics years 2011-2014. Analysis by sector and ICD-10- notification year. Source: Inail

### 1.1.4 Causes of Musculoskeletal Disorders

Several occupational exposures are associated with an increased risk of musculoskeletal disorders (MSDs), including postural stress from prolonged sitting, standing, or awkward position; stereotyped and repetitive tasks leading to chronic diseases; peak overload injuries to the axial or peripheral skeleton; forceful exertions, awkward body posture, environmental factors; and psychosocial [78, 79]

In fact, work-related MSDs occur when the physical capabilities of the worker do not match the physical requirements of the job. Prolonged exposure to ergonomic risk factors can cause damage a worker's body and lead to MSDs.

The main risk factors for the biomechanical overload of the wrist and upper limbs generally are:

*Physical load*

- Repetitive Work: Excessive repetition of movements can irritate tendons and increase pressure on nerves;

- Frequency of repetition and speed: Motion, such as increased speed or acceleration when bending and twisting, can increase the amount of force exerted on the body; Inadequate recovery time due to overtime, lack of breaks, and failure to vary tasks can leave insufficient time for tissue repair;

- Force used during the work: Compression, from grasping sharp edges like tool handles, can concentrate force on small areas of the body, reduce blood flow and nerve transmission, and damage tendons and tendon sheaths;

- Painful/ Tiring positions: Static postures, or positions that a worker must hold for long periods of time, can restrict blood flow and damage muscles; Awkward postures, or unsupported positions that stretch physical limits, can compress nerves and irritate tendons; Compression, from grasping sharp edges like tool handles, can concentrate force on small areas of the body, reduce blood flow and nerve transmission, and damage tendons and tendon sheaths;

- Carrying or moving heavy loads

*Work environment*

- Poor workspace layout, poor design of tools and machinery can result in adopting stressful working postures and applying force;
- Temperature of the workplace affects the body muscles: excessive heat increases overall fatigue and produces sweat which makes it hard to hold tools, requiring more force; excessive cold can make the hands feel numb, making it hard to grip and requiring more force; every movement and position involving more effort are more likely to develop work-related neck and upper limb disorders (WRULDs).
- Poor lighting can create glare or shadows that may require workers to adopt awkward positions to see clearly what they are doing;
- High levels of noise may cause the body to tense in static body postures resulting a more rapid onset of fatigue;
- Vibration can cause damage to nerves and blood tissues as well as other soft tissues. Hand-arm vibrations cause tingling and numbness, or loss of sensibility, requiring a higher clamping force and awkward body positions because vibration hand tools are harder to control.

*Individual factors*

Individual variability refers to: muscle strength, psychomotor skills [80, 81]. The workers' different body dimensions can lead to poor postures when working at a shared workstation. Individual and lifestyle factors includes: gender, age, medical history, physical capabilities; obesity: the anthropometric characteristics of obese handlers are linked to a significant increase of peak lumbar loading [82]; smoking; acute trauma; pregnancy; lack of work experience, training or familiarity with the job.

In particular for the ***gender***, seems that women report more WRULDs than men. However, there is no evidence that gender per se is a significant factor for the development of MSDs [83]. Job characteristics differ between men and women. Men are more often employed in jobs with a higher exposure to physical risk factors, while typical women tasks involve a combination of physical factors (e.g. prolonged standing and sitting, forced postures, job involving moving people and repetitive work) and psychosocial factors (e.g. time pressure). The gender difference could also be linked to differences in exposure to constraints at work or at home, household work, childcare . [83] Beides, ***Age*** represents a susceptibility factor, because the functional capacity of soft tissues, resistance to stress, muscle strength decrease with age. [84] Furthermore is important to list even the accumulation of years of exposure to occupational demands and recent changes in work organization which have led to atypical career paths, precarious working conditions and instability of a job .

*Organizational and Psychosocial factors*

These factors, linked with the way work is designed, organized and managed, as well as to the economic and social context of work, may create an increase of the stress, leading to serious deterioration of mental and physical health [76]. (**figure 13**)

Examples of this type of workload factors include: Highly demanding work; Poor control/scope for decision-making; Lack of social support (from superiors, colleagues); Insufficient gratification;

Dissatisfaction with work; Workplace insecurity; lack of work breaks Monotony, poor job design, no task variation, working under time pressure and deadlines[85].

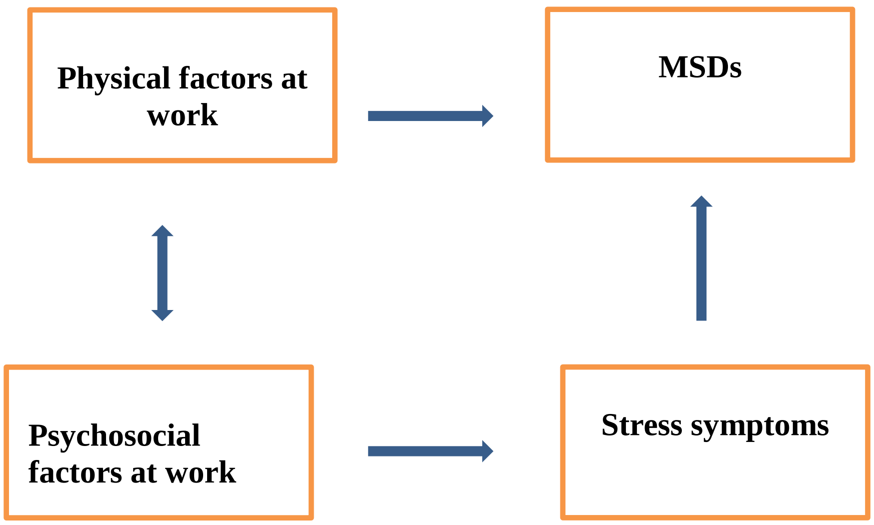



**Figure 13** Possible association between psychosocial factors at work and MSDs*

*source oshwiki.eu, collaborative online encyclopaedia of accurate and reliable information on occupational safety and health (OSH).

According with NIOSH [2] is possible to summarize the risk factors associated with biomechanical overload of upper extremities as described in **table 5.**

In particular for the hand-wrist district, a well-known risk factor is represented by extreme positions of the wrist [2, 86]. Repetitive work has been associated with an increased risk of musculoskeletal symptoms of the wrist and forearm [2, 87, 88]. With exposure to both extreme postures and repetitive tasks it has been suggested that the risk increases, compared with exposure to only one risk factor [2].

| Body part *Risk factor* | Strong evidence (+++) | Evidence (++) | Insufficient evidence (+/0) | Evidence of no effect (-) |
|---|---|---|---|---|
| **Neck and Neck/shoulder** | | | | |
| *Repetition* | | • | | |
| *Force* | | • | | |
| *Posture* | • | | | |
| *Vibration* | | | • | |
| **Shoulder** | | | | |
| *Posture* | | • | | |
| *Force* | | | • | |
| *Repetition* | | • | | |
| *Vibration* | | | • | |
| **Elbow** | | | | |
| *Repetition* | | | • | |
| *Force* | | • | | |
| *Posture* | | | • | |
| *Combination* | • | | | |
| **Hand/wrist** | | | | |
| Carpal tunnel syndrome | | | | |
| *Repetition* | | • | | |
| *Force* | | • | | |
| *Posture* | | | • | |
| *Vibration* | | • | | |
| *Combination* | • | | | |
| Tendinitis | | | | |
| *Repetition* | | • | | |
| *Force* | | • | | |
| *Posture* | | • | | |
| *Combination* | • | | | |
| Hand-arm vibration syndrome | | | | |
| *Vibration* | • | | | |
| **Back** | | | | |
| *Lifting/forceful movement* | • | | | |
| *Awkward posture* | | • | | |
| *Heavy physical work* | | • | | |
| *Whole body vibration* | • | | | |
| *Static work posture* | | | • | |

**Table 5** Evidence for causal relationship between physical work factors and MSDs

### 1.1.5 Preventing musculoskeletal disorders

#### *1.1.5.1 Primary prevention*

In the workplace, the interventions concerning the employer and the employees, screening can be procedure in the workplace with standardized questionnaires looking for early signs or manifestations, internal healthcare, awareness programs, and internal healthcare education systems.

This early intervention can be inserted in the components of work legislation, and guidelines programs. Since in some sectors the access to welfare structures and occupational health services is limited, even specific interventions to increase workers' coverage are necessary.

The role of the employer on the early intervention and the early diagnosis is important because he is the manager of the company and of the workers. Keeping older workers in the workforce, as well as making workplace adjustments for individuals with health problems, could help address the need for skilled labour. Many jobs involve activities that can constitute a risk factor for MSDs. It's important to point out that much can be done to prevent work-related MSDs and minimize risk factors, all of which can be promoted by the employer:

- Healthier lifestyles
- More physical fitness
- Ergonomics
- occupational health and safety such as protective gear
- psychologically healthy work places.

#### 1.1.5.1.1 Legislation

At the international level, the International Labour Organization (ILO) has issued several conventions that relate to MSDs. Before these conventions became legal obligations, they had to be ratified by a certain number of States. The International Organization of Standardization (ISO) has also published international standards, which deal with ergonomic requirements at work stands, methods of risk assessment and other aspects related to MSDs. The European legal requirements regarding musculoskeletal disorders include international conventions and standards, European Directives and European standards. Here summarized the most important international standards [89].

At the international level, International Labour Organisation (ILO) conventions:

• C127 – Maximum weight (loads)

• C148 – Working environment (air pollution, noise, vibration)

• C155 – Occupational safety and health (obliging employers to ensure that workplaces, machinery and equipment are safe)

• C167 – Safety and health in construction

• C184 – Safety and health in agriculture

At European level, EU Directives:

• 89/391/EEC - General Framework Directive, obliging employers to safeguard workers' safety and health

• 89/654/EEC - Minimum safety and health requirements for workplaces

• 89/655/EEC - 89/656/EEC - Work equipment and personal protective equipment

• 90/269/EEC - Employers' obligations concerning the manual handling of loads when there is a risk of back injury

• 90/270/EEC - Minimum safety and health requirements for work with display screen equipment

• 93/104/EC - Organisation of working time

• 98/37/EC – Laws relating to machinery

• 2002/44/EC - Exposure limits and values for hand-arm and wholebody vibration

• 2006/42/EC – Directive on machinery

International Organisation of Standardisation (ISO) and European EN

standards, adding detail to Directives and enabling them to be implemented:

• EN 614: Safety of machinery – Ergonomic design principles

• EN 1005: Safety of machinery. Human physical performance

Musculoskeletal risks associated with work tasks, and ways of reducing them

• EN ISO 9241: Ergonomic requirements for office work with visual display terminals.

• prEN 13921: Personal protective equipment – Ergonomic principles

• EN ISO 12100: Safety of machinery. Basic concepts, general principles for design

Among the voluntary ISO standards were added:

- Ergonomics ISO 11228-1 -Manual Handling-lifting and carrying
- ISO 11228-2 Manual Handling - Pushing and pulling
- ISO 11228-3 Ergonomics - Manual handling - Handling of low loads at high frequency
- ISO CD 12259 (Technical Report) Ergonomics – Application document for standards on manual handling (ISO 11228 – 1,2,3) and working postures (ISO 11226).

National regulations of interest:

- Directive 90/269/EEC on the minimum safety and health requirements for manual handling of loads, where there is a risk particularly of back injury. Most Member State interpretations of the Directive concentrate on setting maximum loads. Some national laws take a more comprehensive approach, however. The Swedish regulations, for example, cover all work postures and movements. Factory inspectorate guidance on the implementation of the regulations is much wider in scope than the Directive, covering all repetitive work, work postures, ergonomic design of work equipment and areas, and the need for workers to change to different types of work and to take breaks when they feel the need, as well as the more obvious specific matters relating to heavy lifting tasks. Employers have to assess the links between mechanical and psychosocial risk factors for MSDs, and have to provide guidance on how to carry out risk assessments in various situations.

- Directive 90/270/EEC on the minimum health and safety requirements for work with display screen equipment The Directive restricts health surveillance to eye and eyesight tests, but does not focus on other health hazards (especially MSDs). The French and Belgian transposing legislation obliges workers who use display screen equipment to undergo special medical surveillance - the content of which is not specified - which allows the occupational health services to devote more time to preventive health activities for such workers. In Finland the task of medical surveillance has been expressly extended to ‘general health’ and in **Italy** to ‘musculoskeletal disorders’.

A European Directive requires national legislation to be implemented accordingly in each Member State before it comes into effect. Generally, a Directive fixes the agreed objectives to be pursued by the EU Member States, but leaves some freedom of choice for the ways of obtaining them.

***Italy***

In the Italian legislation there is not a specific law addressing the problem of the prevention of MSDs, even if exposure to MSDs risk factors is indirectly recognized as presumptive (under certain conditions) if specific musculoskeletal disorders, included in the new table of diseases mandatorily covered by insurance, from the decree “DM 9/4/2008”, occur. With regard to preventive action is, however, possible to refer to the rules of a more general nature of the recent Legislative Decree 81/08 that dictate guidelines for this issues. Legislative Decree no. 81/08 makes numerous references to ergonomics: the Title I art. 15 asks the employer "the observance of ergonomic principles" in the organization of work, in the design of workplaces, the choice of equipment and in the definition of the methods of work and production, in particular in order to reduce the health effects the monotonous and repetitive.

Article 28 of the same Decree. 81/2008 also establishes the obligation for the employer to take action through organizational measures and appropriate means to reduce the risk, and this covers all risks, including the biomechanical overload of the upper and lower limbs that can lead to musculoskeletal disorders. Specifically the Article 28, paragraph 1, states that: The assessment referred to the article 17, paragraph 1, letter a), even in the choice of work equipment and substances, as well as in the layout of the workplace, must cover all risks for the safety and health of workers, including those for groups of workers exposed to particular risks, as well as those related to gender, age, from other countries." It is also clear that the Risk Assessment Report must contain: the criteria used for evaluation; an indication of the measures of prevention implemented and PPE adopted, the program of measures considered necessary for the improvement of safety levels over time, an indication of those who participated in the risk assessment. In the case of health risks, the company physician should define the health surveillance protocol.

Concerning the methods to be used to assess the risk of loads manual handling, the art. 168 paragraph 3 of the Decree specifies that: The "technical rules" are benchmarks for the purposes of this Article and Annex XXIII, where applicable. In other cases, you can refer to good practices and guidelines.

The Lombardy Region with decree n. 3958 of 22 April 2009 approved the document "Guidelines for the prevention of regional musculoskeletal disorders and repetitive strain associated with movements of the upper limbs - updated edition 2009" [90]. The Guidelines were developed in the context of the Regional Plan 2008-2010 for the promotion of safety and health at the workplace, in order to define a path for the prevention of MSDs.

It should be emphasized that even if on the one hand, in the absence of a specific regulatory articulated, the risk assessment can be carried out with methods "freely" chosen by the employer (provided accredited in literature and still explicit in its assessment document) from on the other side of the matter it has recently been adopted by ISO technical standard (standard) of voluntary that can be a point of reference to make such assessments.

Among the voluntary ISO The standard “ISO 11228-3, Ergonomics - Manual handling - Handling of low loads at high frequency” fully meets the definition of technical rule of Art. 2 of Legislative Decree 81/08; is sufficiently flexible in offering different accredited methods from the literature and, overall, the system is fully compliant with the Lombardy region guidelines by providing stages of risk identification, estimation simplified risk and, finally, of its detailed assessment through selected methods of analysis.

For identification of methods and criteria for assessing the risk from repetitive movements of the upper limbs ISO 11228-3 cites among the others: OCRA, HAL and the STRAIN INDEX methods. Here below a summary of useful methods products in the literature that address the assessment the risk of repetitive movements. (**table 6**)

| | | | |
|---|---|---|---|
| **OWAS** | Owaco Working Analyzing System identifies the most common work postures for the back (4 postures), arms (3 postures) and legs (7 postures) and the weight of the load handled. (3 categories) | **Quantitative** | **Whole Body** |
| **RULA** | Rapid Upper limbs is a screening tools that assesses biomechanical and postural loading on the whole body with particular attention to the neck, trunk and upper limbs. | **Quantitative** | **Upper limb** |
| **REBA** | Rapid Entire Body Assessment is a screening tool as RULA, observation of body segments and the deviation from the neutral posture. Group 1 includes trunk, neck and legs. Groups 2 includes upper arms, lower arms and wrist. | **Quantitative** | **Whole Body** |
| **PLIBEL** | A simple check list screening tool intended to highlight musculoskeletal risk in connection with workplace investigations. Time aspects, environmental factors and organizational also have been considered as modifying factors. | **Quantitative** | **Whole Body** |
| **STRAIN INDEX** | Strain Index is a semi quantitative method. This method involves the measurements of six task variables such as intensity of exertion, duration of exertion per cycle, efforts per minute, speed posture, speed of exertion and duration of task per day. Specific postures are defined by angulation degree for the movement of flexion, extension and abduction of the wrist. | **Quantitative** | **Upper limb** |
| **QUEC** | Quick exposure Check is a quick check list who considers the posture of back, wrist/hand, shoulders/arms, the weight handled, daily time in task, force, visual demands, vibrating tools… | **Quantitative** | **Whole Body** |
| **HAL/TLV**<br>**ACGIH** | Evaluation of tasks with repeated lifting. The location of the handled material related to the body is divided on space with matrix of four vertical three horizontal distances. | **Quantitative** | **Upper limb** |
| **OCRA INDEX** | The Occupational Repetitive Action Index is a synthetic index describing risk factors of repetitive actions at work with one figure. It is quantifies the relationships between the daily number of actually performed by the limbs in repetitive tasks, ad corresponding number of recommended actions. | **Quantitative** | **Upper limb** |
| **OCRA Check list** | The OCRA checklist is an ergonomics tool for prevent the MSDs on upper limb, it consider the repetitiveness, the frequency, the force, the awkward posture. This Checklist consider too the duration of the job. | **Quantitative** | **Upper limb** |

**Table 6** Ergonomics methods to assess the MSDS (ISO 11228-3)

Risk assessment methods available in literature and related issues will be described in the following paragraph.

#### 1.1.5.1.2 Job analysis methods

In order to prevent work-related musculoskeletal disorders it is fundamental to record and assess physical workloads at the workplace. In particular, risk assessment of physical workloads is an important part of the risk management process. It comprises a multistep approach to improve workplace health and safety and productivity [91]. The general five steps of the risk assessment procedure involve identifying hazards and those at risk, evaluating and prioritizing risks, decisions on preventive actions, executing actions and finally monitoring and reviewing at regular intervals. Among executing actions there is even the health surveillance.

All five steps require precise knowledge of the physical workload factors and an estimate of the associated risks at workplaces. This involves recording physical workload factors associated with work-related musculoskeletal disorders in order to adopt suitable and relevant ergonomic prevention measures.

Recording and assessing physical workload factors means considering numerous methods available, ranging from interviews and surveys, field measurements and video-analysis up to laboratory measurements and simulations. However, these methods differ among other things in terms of the precision obtained in the recording and assessment of workloads and in terms of user groups. The assessment often targets the risk to a certain region of the body (e.g. the spine or the wrist). (https://oshwiki.eu/wiki/Assessment_of_physical_workloads_to_prevent_work-related_MSDs).

Various reviews of MSD risk assessment methods have been published.

They include:

— ISO 11228-3 (2007) Ergonomics - Manual handling - Part 3: handling of low loads at high frequency.

— Neumann, P. (2006) Inventory of tools for ergonomic evaluation inventory of tools for ergonomic evaluation, Stockholm: National Institute for Working Life.

— Occupational Health and Safety Council of Ontario (2008) MSD Prevention Toolbox. Part 3C: more on in-depth risk assessment methods, Toronto: OHSCO.

— Takala, E.-P. et al. (2010) 'Systematic evaluation of observational methods assessing biomechanical exposures at work', Scandinavian Journal of Work, Environment and Health, 36 (1), 3-24

Considering the criteria of the IFA – Institute for Occupational Safety and Health of the German Social Accident Insurance [92] we can observe in **Figure 14** the basic categories of methods for recording and assessment of physical workloads at the workplace with their potential user groups.

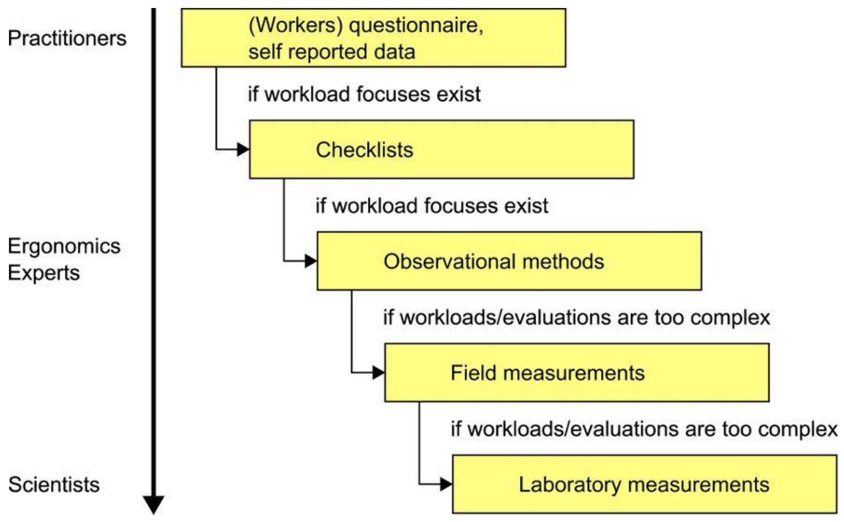



**Figure 14** Basic categories of methods for recording and assessment of physical workloads at the workplace and potential user groups (source IFA, 204)

The top category (*Level ,* **figure 14**) includes questionnaires and self reported data. In this category workers are required to estimate retrospectively the occurrence and frequency of their daily amount of physical workload. In literature, epidemiological studies on work-related MSDs often use self-reported data for exposure assessment. Nevertheless, these methods seems to be inaccurate for workload assessments, as the workers' ability to estimate their physical exposure is limited and workers that already suffer from MSDs tend to overestimate their exposure. In the *Level 2 (***figure 14**) category, checklists are used to identify workload focused at the workplace. Normally checklists contain limiting values for the assessment of specific physical workload types. If these limiting values are exceeded, workload focuses can be identified. [93]

If the job analysis underlines the existence of activities such as lifting and carrying of loads, it is advisable to employ more specific observational methods (*Level 3,* **figure 14** ) in order to assess the associated risk factors a little more precisely. Examples for screening observational methods in this category are the Finnish OWAS method [94] and some newer methods like the Key Indicator Methods (KIM) [95,96,97] and the MAC tool (*Manual handling assessment chart, 2003)* [98] that address lifting and carrying, pulling and pushing and manual work processes and the ART [99] tool for assessing repetitive tasks. Other available tools are shown below, some of them more suitable for identifying solutions(e.g. Psychophysical tables, SOBANE) , some others helpful as screening or analysis tools such as RULA[100], Strain Index [101], OCRA [102], HAL [102], FIFARIM, Risk Filter and Risk Assessment Worksheets, PLIBEL, Keyserling Checklist, NIOSH equation.

For certain types of work, such as activities involving physical exertion or awkward postures, there are few observational assessment methods. An example of an expert observational method for the assessment of activities involving physical exertion and/or exposure to force is the Exertion Atlas developed under the supervision of the Institute of Ergonomics of Darmstadt Technical University (IAD). For the assessment of different types of workload and particularly for cyclic activities in the automotive and supply industry, the IAD has developed the AAWS (Automotive Assembly

Worksheet) [105] and the EAWS (European Assembly Worksheet) [106] in this category.

Observational methods have several limitations cause often a good risk assessment depends from the expertise of the observer and sometimes they only roughly classify workload categories and often do not adequately reflect the complexity of work processes [107]. In particular, three-dimensional movements, such as the torsion and lateral flexion of the back, cannot be recorded with great accuracy using observation methods [74]. Furthermore, it is not possible to appropriately record and assess the pattern of stressing and rest over time. Same situation if we need to evaluate the effort exertion. Therefore some applications necessitate the performance of measurements of physical workloads directly at the workplace (field measurements, Level 4).

A number of measuring systems have been developed for the recording and analysis of body posture and movements in the work process. Most of these are designed specifically for the recording of the movement of parts of the body, e.g. the back [108,109] but even upper limbs. One example of a field measuring system that allows for long-time analyses (e.g. for an entire work shift) is the CUELA ("computer-aided recording and long-term analysis of musculoskeletal workloads") measuring method [92, 110]. It permits the continuous recording and analysis of physical workload factors directly at the workplace. Another method is the surface electromyography that allows to record the muscle activation during the working activities and estimate the fatigue. Given prior training, field measuring methods can be applied with a degree of effort comparable to that for the expert screening method.

Depending on the application, the field measuring methods permit an assessment on the basis of biomechanical, energy/cardiopulmonary, muscular, psychophysical and epidemiological criteria. The limitations of measuring methods at the workplace include limitations in terms of the measurement accuracy (e.g. for measurements of exertion) characteristic of field measurements in real working conditions.

This is where laboratory measurements (Level 5) in which work processes are replicated under standardized experimental conditions yield the most precise data on the physical workload situation. Such laboratory measurements for the analysis of several activities as nursing and for specific workloads [111,112,113] have been conducted.

Finally, efforts should be made to interlink the methods of all levels and precisely present the assessment principles. As a result it would be possible to identify gaps in the knowledge, develop the methods on all levels further and eliminate discrepancies in the assessment results.

Examples of gaps in the knowledge include the lack of approaches for the assessment of awkward postures and a consideration of both the risks of under-stimulation and of the pattern of stressing and rest (recovery phases) over time. The goal for prevention is to recommend the right degree of workload and thus prevent both occupational overload as well as under-stimulation, e.g. from lack of exercise.

For the assessment of the risks associated with specific work-related musculoskeletal diseases, e.g. Carpal Tunnel Syndrome (CTS), there is a need for assessment methods that do justice to the associated specific risk factors. [85]. Also relevant to CTS are assessments of the speed and frequency and the forceful of wrist movements that are virtually impossible to determine using observational methods.

The development of methods that combine recording and assessment of physical and mental/psychosocial workloads at the workplace therefore is needed [85]. Recent studies in fact suggested that ergonomic risk evaluation techniques, self reported body part questionnaires and physical measurement of physiological/biomechanical transients may have a relationship and can be used for the evaluation of work related musculoskeletal disorders. [114].

The choice between the methods available will depend upon the application concerned and the objectives of the study. General, observation-based assessments appear to provide the levels of costs, capacity, versatility, generality and exactness best matched to the needs of occupational safety and health practitioners (or those from related professions) who have limited time and resources at their disposal and need a basis for establishing priorities for intervention . [115]

Since, taking into consideration the voluntary ISO standard 1128, and based on the available data, it can be concluded that the joined application of the strain index method and the surface electromyography are the most suitable methods to assess wrist risk, a specific description of these tools will be provided in the next paragraphs.

### *Strain Index*

Strain Index (SI) is a semi-quantitative method for identifying high-risk jobs by calculating an overall numerical score - the "Strain Index". The method was developed by Moore and Garg in 1995 to assess exposure for the upper extremities. The body regions mostly interested are the wrists and hands. It is intended for professional and ergonomic teams to predict the raised risk of developing an MSD.

The method consists in:

— Collecting data for six risk factors: intensity of exertion, duration of exertion,
exertions per minute, wrist/hand posture, speed of work, and duration of task
per day. A video recording of the work is also recommended.

— Scoring each factor (from 1–5) by reference to one or more qualitative and
quantitative criteria. The study is made easier by the fact that each partial score
is validated by a range of observations and/or measurements.

— The final score - the "Strain Index" – is calculated by multiplying the six coefficients
obtained.

A score > 7 indicates probably a hazardous job and a score < 3 a safe job. One of the unique advantages of this method is that the assessment of postures, efforts and pace is based not on one single criterion but on 2 to 5 quantitative and qualitative criteria of the observer and workers. This gives it greater reliability. This is a method for use by health and safety officers because training in ergonomics is needed for the scoring. Once the study to determine a representative work procedure is done, the method can be gone through quite quickly in 45 mins/1 hour. It requires a discussion with the workers to get their perceptions of efforts, postures and paces, and to achieve reliable scores. The Strain Index concerns only MSDs of the wrists and hands. In this limited – but the biggest (carpal tunnel syndrome, etc.) - field it has often been used to quantify risks and compare different work situations. It has a fairly good benefit cost ratio: it is easy to use and produces a fairly reliable risk score where such quantitative assessments are wished for. The method is purely for assessing risk factors, not preventing risks, although the consultation that is needed with workers can be used to discuss preventive measures and improvements.

Strain Index has been used for several studies to assess the biomechanical overload of the upper limbs [116].

The evaluation provided by these methods does not take into account mental exertion which together with physical exertion can cause an increase of accidents and a decrease of production [117, 118]

### *Surface Electromyography*

Skeletal muscles generate active forces for the static and dynamic motor functions within the human body when acting upon the bone and joint system. The position and the movement performances of the human body are based on the activation of a single or a multitude of muscles. The biomechanical approach aims to assess these performances by kinematic measurement and kinetic description on the basis of physical model [119].

The electrophysiological activation of a muscle initiates the mechanical force production. This muscle activity can be observed as surface electromyography (EMG, sEMG) and reflects the degree of activation: the higher the EMG level, the more the force is developed by the muscle . [119] The sEMG activity is picked up by surface electrodes placed on the skin, above the belly of the biceps muscle and quantified by double wave rectification and moving average with an averaging interval of about 100–200 ms.

Biochemical and physiological changes in muscles during fatiguing contractions are, namely, reflected also in properties of myoelectric signals recorded on the surface of the skin above the muscle(s) concerned [120]. sEMG picks up the summation of the electrical activity of all the motor units that are in its detection range. The information reveals the general muscle state. The amplitude of the sEMG signal varies from µV to the low mV .

In biomechanics, three applications dominate the use of the surface EMG signal: its use as an indicator of the initiation of muscle activation, its relationship to the force produced by a muscle, and its use as an index of fatigue processes occurring within a muscle. [121]

Although simple to determine, results obtained in this manner depend also on psychological factors like motivation, associated with task conditions [122]. In spite of the limitations of the application of sEMG method to muscles positioned directly below the skin, and the problems of cross talk of myoelectric signals from neighbouring muscles, the method, due to its advantages, is used even more often to determine local muscle fatigue. With increased knowledge about the indicators of muscle fatigue, it should be possible using initial parameters to predict how long an exertion can be performed. It has been observed that the frequency parameters are the most reliable for making predictions.

Its principal advantages, in this respect are (1) non-invasiveness, (2) applicability in situ, (3) real-time fatigue monitoring during the performance of defined work, (4) ability to monitor fatigue of a particular muscle and (5) correlation with biochemical and physiological changes in muscles during fatiguing. [123]

The advantage of this EMG method is that individual capabilities and task aspects are integrated: each worker performs his working tasks in his own way, depending on his capabilities. When his capabilities are no longer sufficient, he may adopt poor movement patterns, which may lead to overload risks. With this prediction method, overload disorders can be avoided. We may conclude from the applied research that the use of EMG in the working environment is feasible and in many cases necessary to avoid complaints or reduce their amount. The information obtained from EMG cannot be obtained in any other way, and defines how a person with certain capabilities copes with a load. It has been used since early 1950s, when Lundervold [124] used EMG to investigate muscle activity in patients with so-called 'occupation myalgia'. 'Occupation myalgia' was defined as pain in muscles overstrained as a result of unvaried work (i.e. static work).

Similar recordings and analyses have been performed in the textile, car assembly and tertiary sectors and farming [126].

The EMG is highly variable and is dependent upon electrode application and placement [127], perspiration and temperature [128], muscle fatigue [129], contraction velocity and muscle length, cross talk from nearby muscles, activity in other synergists and antagonists [130], subcutaneous fat thickness, and slight variation in task execution, to name a few. Therefore, when comparing amplitude variables between measurements, normalization of some kind is required, i.e. the EMG signal is converted into a scale that is common to all measurement occurrences. Normalization controls for the aforementioned variables and facilitates the comparison of EMG signals across muscles, between subjects, or between days for the same subject. Previous studies have used a number of different methods to produce reference EMG values for normalization purposes that can be repeated across participants and test days, including isometric, isokinetic and dynamic muscle actions [131,132,133], Table 7.

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**at the University of Milan**
**Director: Prof. Giovanni Costa**

| Normalization method | | Advantages | Disadvantages/Limitations | Data interpretation |
|---|---|---|---|---|
| Isometric method | *MVC method* | Perhaps the most powerful strategy for physiologic interpretation in healthy people. | ○ Poor reliability.<br>○ Is affected by inertial effects at the onset of the test, patient fatigue, patient posture, synergistic contribution, patient motivation, pain, neuro-muscle-skeletal dysfunctions and neurologic conditions.<br>○ May not represent the maximum activation capacity in other lengths or under non-isometric conditions. | Represents the percentage of the maximum neural drive acquired while a subject performs an isometric MVC of the desired muscle.<br>Any change in EMG amplitude indicates a true increase or decrease in the neural drive. |
| | *Submaximal voluntary method* | Resolves the instability of the EMG signal at near maximal levels. | ○ Inter-subject coefficient of variation generally increases by using either 50% of the isometric MVC.<br>○ Values can be lower than the obtained during the activity.<br>○ Is affected by inertial effects at the onset of the test, patient fatigue, patient posture, synergistic contribution, patient motivation, pain, neuro-muscle-skeletal dysfunctions and neurologic conditions.<br>○ Does not represent a dynamic contraction. | Percentage of the maximum neural drive acquired while a subject performs an isometric submaximal voluntary contraction of the desired muscle.<br>Any change in EMG amplitude indicates a true increase or decrease in the neural drive. |
| | *RVC method* | Helpful for clinical populations who are unable to attempt maximal efforts or who need a similar controlled task for interpreting repeated tests. | ○ Is affected by inertial effects at the onset of the test, patient fatigue, patient posture, synergistic contribution, pain, neuro-muscle-skeletal dysfunctions and neurologic conditions.<br>○ Does not represent dynamic contraction. | Any change in normalized EMG amplitude indicates a true increase or decrease in the neural drive. |
| Isokinetic actions | *Isokinetic MVC method* | Has been used as a method to simulate with a higher degree of comparability muscle contractions obtained in dynamic activities. | ○ Is less reliable than the other normalization methods. | Represents the percentage of the maximum neural drive acquired while a subject performs an isokinetic MVC of the desired muscle.<br>Any change in EMG amplitude indicates a true increase or decrease in the neural drive. |
| Dynamic muscle actions | *Mean dynamic method* | Reduces the inter-subject variability in relation to other normalization methods.<br>Helpful for clinical populations that are unable to attempt maximal efforts. | ○ Tends to produce a normal EMG template for a particular task and, therefore, may remove the true biological variation within a group.<br>○ It may be more susceptible to systems with a low signal to noise ratio or represent baseline noise in movements that cause very phasic activation.<br>○ It does not give an indication of what this activity level means with respect to the muscle's ability to activate. | Represents a percentage of the average of both quiet and active periods during the activity. |
| | *Peak dynamic method* | Reduces the inter-subject variability in relation to other normalization methods.<br>Helpful for clinical populations that are unable to attempt maximal efforts. | ○ Tends to produce a normal EMG template for a particular task and, therefore, may remove the true biological variation within a group.<br>○ It does not give an indication of what this activity level means with respect to the muscle's ability to activate. | Indicates at what periods during the activity the muscle is most active. |

**Table 7** Advantages, disadvantages/limitations and interpretation of normalization methods.

**Parameters**

There are several techniques for data processing using the raw sEMG-signals. One of the common one mostly used in the studies mentioned above is the estimates of sEMG amplitude.

Modulation of the amplitude due to muscular effort and/or fatigue represents the dominant change of sEMG signal in the time domain. First continuous EMG amplitude estimators consisted of full-wave rectifier followed by a resistor–capacitor low-pass filter [134].

In modern digital systems two indicators of sEMG amplitude are used: mean absolute value (MAV), also called average rectified value (ARV), and **root-mean-square (RMS**) value. They are defined by following equations:

$$\mathrm{MAV} = \frac{1}{N}\sum_{i=1}^{N}|x_i| \qquad \text{a)}$$

$$\mathrm{RMS} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}x_i^2} \qquad \text{b)}$$

a) Equation a: mean absolute value

b) Equation b: root-mean-square (RMS)

In both equations xi is the *i*th sample of a signal and N is the number of samples in the epoch. According to Clancy et al. [135] the amplitude of the single channel sEMG signal can be estimated using cascade of five sequential processing stages: (1) noise rejection/filtering, (2) whitening, (3) amplitude demodulation, (4) smoothing and (5) relinearization (**Figure 15**)

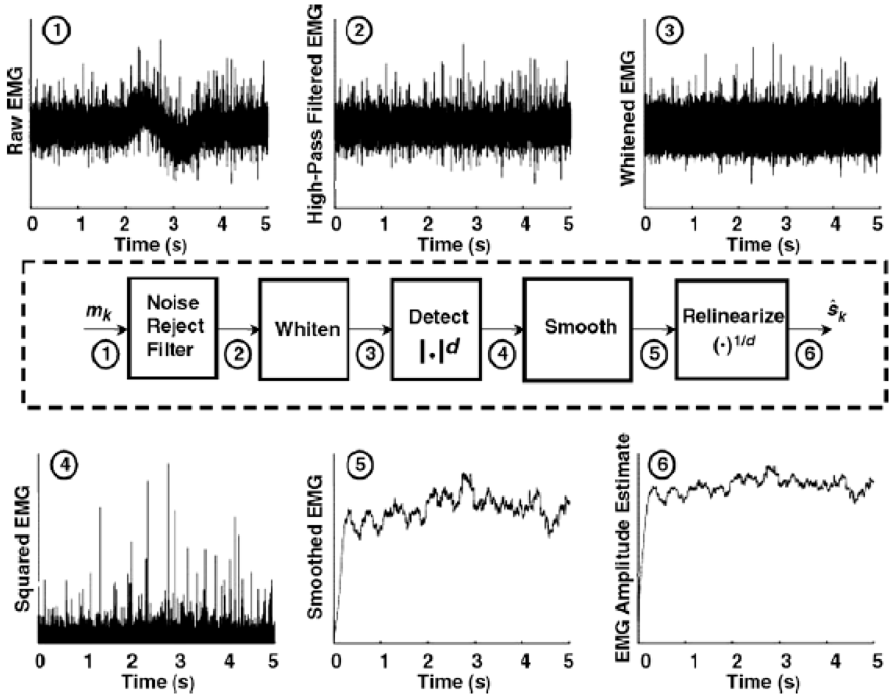



**Figure 15** Cascade of processing stages used to form an EMG amplitude estimate.

The EMG amplitude estimate is $\hat{s}_k$. In the ‘‘detect” and ‘‘relinearize” stages d = 1 for MAV, and d = 2 for RMS processing. [135]

It is possible to obtain a profile of the muscular load during a period of work by analyzing the **amplitude probability distribution** of the myoelectric signal. The analysis can be described by the following steps: 1) full-wave-rectification and low-pass-filtering (**Figure 15**); 2) A/D-convection (**Fig. 16 A**); 3) drawing an amplitude distribution histogram (**Figure 16B**), which can be changed to a cumulative amplitude distribution histogram (**Figure 16C**); 4) the amplitude probability distribution curve (**Figure 16D**) obtained on the basis of the histogram.

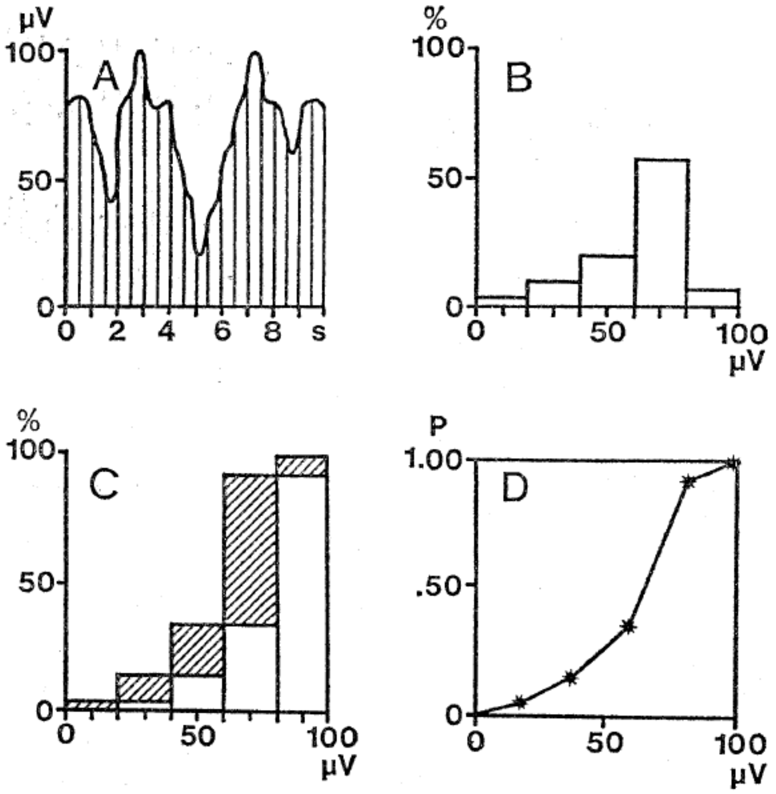



**Figure 16** Analyze the amplitude probability distribution **of** the myoelectric signal

From the low-pass-filtered myoelectric signal (A) subsequent samples are obtained: an amplitude distribution histogram (B) and a cumulative amplitude distribution histogram (C), which in turn can be converted into an amplitude probability distribution curve (D). [136]

The amplitude probability at a certain level of contraction is the probability of the myoelectric activity being lower than or equal to that contraction level.

The amplitude probability at a certain level can be expressed as a fraction of the total duration that the signal is lower than or equal to this level. If the myoelectric signal amplitude values are converted into relative force values (% MVC) by comparison with a calibration function, then the amplitude probability distribution function of the myoelectric signal amplitude can be converted into an amplitude probability distribution function of the relative force of contraction during the period of work (**Figure 17**). [136]

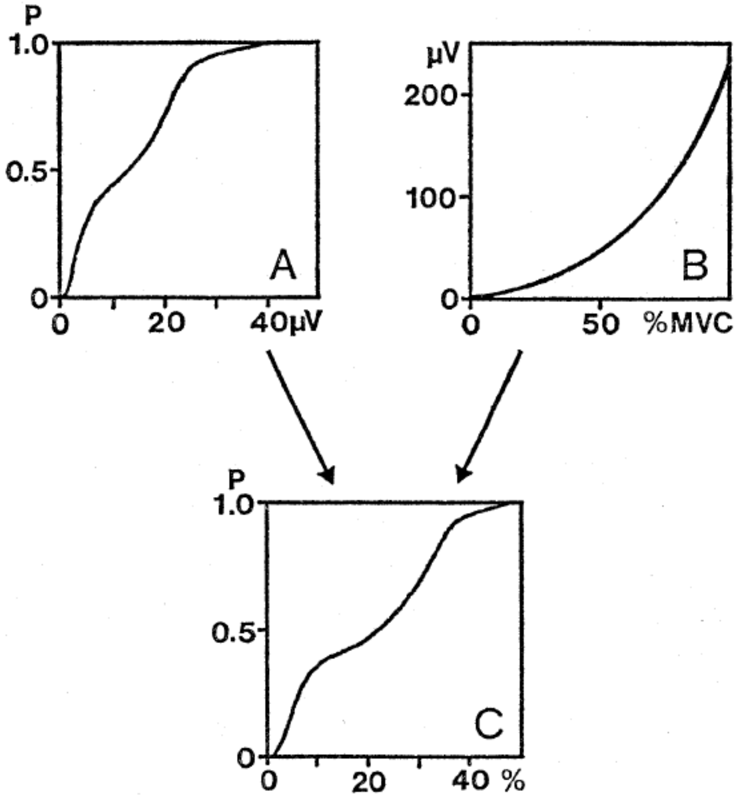



**Figure 17** The amplitude probability distribution of the myoelectric signal

(A) when combined with the calibration function (B) will result in the amplitude probability distribution function of the relative force of muscular contraction (C). [136]

The level of contraction or of myoelectric signal amplitude where the amplitude probability distribution curve starts at the probability level P=0 indicates the lowest level of muscular contraction which has occurred during the whole work period. This level is referred to as the level of "static contraction" during the work period. In almost all cases this level is zero or very close to zero when long term recordings are analyzed. Also in a very typical static work situation there are short periods of **muscular rest**. If, on the other hand, the "static" level is defined as the level of muscular contraction corresponding to probability level P=0.1 (allowing muscular rest during no more than 10 % of the total recording time), then it is quite common to find that the trapezius activity may have a static load level of 2-10% MVC. The level of contraction or of myoelectric signal amplitude where the amplitude probability distribution curve stops at probability level P=1 indicates the level of the highest level of muscular contraction which has occurred during the whole work period. In many cases, this level is very high due to the fact that the calibration curves obtained from the test contractions are not always quite reliable at the highest contraction levels. If, on the other hand, the level of these peak loads are determined at the probability level P=0.9 (allowing the muscular contraction to be higher during no more than 10% of the total recording time), then this level of the peak loads will usually give relevant information. In the cases where the estimated peak loads are higher than 50% MVC and where the EMG activity has been normalized to a test contraction at approximately 30 % MVC, then the level of contraction corresponding to P=0.9 will sometimes be unrealistically high, in some cases more than 100 % MVC. The contraction level might be overestimated but seldom underestimated at higher levels of contraction. The level of contraction or myoelectric signal amplitude corresponding to the probability level P=0.5 will indicate the median level of contraction during the whole working period. In most cases, this median level is close to the mean level of contraction obtained from integration of the myoelectric signal amplitude or by RMS-detecting the myoelectric signal.

The amplitude probability distribution curve will in a characteristic way reflect how the muscle has been working during the recording period. [136]

Jonson in 1982 defined even the limits values for the muscular load. Based on studies of muscular endurance during constrained static and dynamic work the following limit values have been suggested for constrained work with a duration of one hour or more [136]: the static load level should not exceed 2 % of MVC and must not exceed 5 % of MVC; the mean (or median) load level should not exceed 10% of MVC and must not exceed 14% of MVC; and the peak loads should not exceed 50% of MVC and must not exceed 70% of MVC.

These and similar suggested limits have been suggested by Johnson as criteria in the analysis of the amplitude probability distribution curve of the relative force of contraction in vocational studies: the limit which should not be exceeded when the amplitude probability distribution curve for the full day of work (scheduled rest periods not included) is estimated; the limit which should not be exceeded for continuous work for more than one hour; the limit which should not or or should only occasionally be exceeded for continuous work for more than 10 min. [136].

Lastly, in such a work task, the importance of short pauses (EMG gaps) have been evaluated, and workers with previous episodes of complaints were shown to have fewer episodes with an EMG amplitude below 0.5% MVE than were healthy subjects [137]. Further, subjects with a low gap frequency have shown a higher risk of developing muscle disorders than subjects with a high gap frequency, while performing highly repetitive work tasks [138]. In an experimental study [139], short EMG gaps sometimes preceded a rotation between motor units during a static contraction. This in turn indicates an ability to raise the threshold of recruitment for an exhausted motor unit, a factor that might protect the muscles in contractions of long duration. Consequently, a high gap frequency might be a personality trait that is connected to a lower risk of muscle disorders. Further, perceived general tension has shown a strong association with shoulder and neck pain [140].

#### *1.1.5.2 Secondary Prevention*

All experts agree that earlier diagnosis followed by appropriately early intervention would in many cases, prevent the MSDs from getting worse and would enable the worker either to stay in work or to return to work as soon as possible. We saw the early diagnosis can be made by ergonomist, doctors, or the employees themselves.

In the domain of the healthcare system, we have interventions on early referral to physical therapy, early access to effective drug therapies for workers with inflammatory conditions, or early access to cognitive behavior therapy for selected patients.

Medical surveillance is one of the primary instruments in occupational health activities and is considered essential to maintain employees' good health. [141]

When dealing with a worker who consults for MSD, the physician's role is not limited to diagnostic and therapeutic aspects but also involves prevention. Occupational history is the key to the clinical evaluation process. By taking a patient's occupational history, the physician can collect information on various risk factors and assess their significance in the development of MSD. The patient's history can also indicate whether other workers are exposed to the same risk factors, which means that the scope of a problem within a company can be assessed. The information acquired during clinical evaluation about the requirements of a job will also be useful when the patient returns to work; it can be used to ensure that relapse or deterioration of a MSD is prevented.

Steps of the risk assessment process:

1. Assessment of the musculoskeletal problem: Make a diagnosis trough screening tools; Document how symptoms appeared; Go over the medical history and history of previous injuries
2. Identification of occupational and non-occupational risk factors and documentation of the significance of these exposures
3. Formulation of a medical opinion on the influence of risk factors on the musculoskeletal problem.

Musculoskeletal disorders (MSDs) have a multifactorial etiology and therefore, a holistic approach to identifying target groups for primary/secondary prevention is essential. [142]

To help define the problem and its relationship to work factors, increasing interest has been directed in many countries to the development of methods to estimate and record musculoskeletal symptoms and screening tools. Questionnaires have proved to be the most obvious means of collecting the necessary data. [143]

This consideration was the main motive for a Nordic group to start developing standardized questionnaire [143] for the analysis of musculoskeletal symptoms, that became the most used tool in researches even with some modifications.

Besides, recent studies suggest that additional studies are needed to further define the sensitivity and specificity of the physical examination maneuvers, as these results suggest they may not be high [144,145,146,147,148,149].

Conclusion Prevalence estimates for common upper extremity MSDs (shoulder tendinosis, lateral epicondyalgia, and CTS) vary widely depending on the epidemiological case definition used. It remains to be determined whether these large variations in prevalence have impacts on purported risk factors [150].

Researchers used a variety of criteria to define MSDs and this largely limited the comparability across studies. Self-administered questionnaires and surveys have been extensively used in the identification of work-related MSDs. But it is not clear how self-reports of pain are related to physicians' diagnoses and physical signs obtained during a structured examination, and how both of them could be best employed to define MSD cases in epidemiologic studies. Pretty often [151,152] seems self-reported pain poorly corresponded to diagnoses assigned by trained nurses for hand and wrist disorders. Substantially, more subjects declared having experienced pain than were assigned diagnoses by the nurses. The Use of self-reported pain versus physical findings could result in different classifications of individuals as MSD cases. Researchers should be aware of potentially relevant discrepancies between self-reported measures and physical examination findings in the design of a study and consequentially intervention effective at improving one measure might be shown to be ineffective at improving the other. Thus, when evaluating the success of an intervention, screening or surveillance programme for work-related MSDs, it seems important to define clearly which measure might be most adequate and should be employed. Other possible source of discrepancy is the not continuous and episodic nature of MSD symptoms, especially when in early stages. These factors could condition that symptom reports might not correspond well to defined clinical syndromes.

## 1.2 Dairy industry

Dairy farming has been practiced all over the world by humans for thousands of years [153]. Milk - also known as white gold - can be used to make an enormous variety of high quality products. The high cost of milk as a raw material has necessitated a high-tech processing industry.

**Italy** is one of the main players of the world dairy industry: the national production combines quality, volumes and tradition. Most advanced milk processing technologies have turned it into a favorite drink – fresh, UHT, LSL – compatible with special diets and accessible to customers suffering from intolerance. [154]

The cheese-making tradition is testified by 37 PDO cheeses and by numerous local cheeses, where the traditional practice has become industrial process, besides cheeses made with modern production technologies. A variety of cheeses that meet the diverse and demanding needs of domestic and foreign consumers.

The dairy sector is the first Italian food division, with a sale of 14,2 billion of euro. 75% of the milk is produced in the North districts of Italy: Lombardy, Emilia Romagna, Veneto e Piemonte. In Italy 11 millions of tons of milk are produced and 13 millions of tons of milk are converted in 1 millions of tons of cheeses, almost 3 millions of tons of pasteurized drinking milk and UHT milk and 190.000 tons of yogurts and fermented milks. Italian dairy industry produces a great variety of traditional cheeses, among those the most famous, mozzarella, occupies the first place as far as volume is concerned – 250,000 tons/year – followed by the two most popular DOP (Protected Denomination of Origin) cheeses in the world: Grana Padano – the most exported with 163,000 tons/year and Parmigiano Reggiano – the most imitated with 116,000 tons/year. Besides, Italy exports almost 250.000 tons of cheese, with a value of 1,4 billions of euro. Much of the livestock sector to address Italian cattle is concentrated in northern Italy, precisely in Lombardy, Emilia

Romagna and Veneto. Lombardy produces about 40 million hectoliters of milk cow per year, accounting for 37% of the national total and are supplying the largest dairy companies. In **table 8** The distribution of the milking parlors in Lombardy region provinces.

| **Lombardy region provinces** | **Number of milking parlors (%)** |
| --- | --- |
| BG: Bergamo | 450 (10.1%) |
| BS: Brescia | 1159 (26%) |
| CO: Como, LC: Lecco | 218 (4.9%) |
| CR: Cremona | 789 (17.7%) |
| MI: Milano, LO: Lodi | 567 (12.7%) |
| MN: Mantova | 775 (17.4%) |
| PV: Pavia | 102 (2.3%) |
| SO: Sondrio | 31 (7%) |
| VA: Varese | 8 (1.9%) |
| Totale stabilimento: | 4457 |

**Table 8** Distribution of milking parlors in Lombardy region by province

Also in the **United States** dairy production has assumed a relevant role in the industry. According to the United States Department of Agriculture(USDA), " America's dairy industry is much more than milk. It's jobs, economic activity and supporting local businesses for the people of our country. The United States is home to a mixture of large and small dairy farms — both of which contribute to the local economy and tax base."

In United States the farm value of milk production is second only to beef among livestock industries and is equal to corn. Dairy products range from cheese, fluid milks, yogurt, butter, and ice cream to dry or condensed milk and whey products. Milk is produced in all 50 States, with the major producing States in the West and North. More than 51,000 U.S. dairy farms provide milk, cheese and yogurt to the United States and other countries. About 97 percent of all dairy farms are family-owned. Dairy farms are generally members of producer cooperatives.

The USDA National Agricultural Statistics Service (NASS) estimated U.S. milk production of 17.1 billion pounds for October 2015, up 0.1 percent from October 2014. Milk cows numbered 9.309 million head, 32,000 head more than October 2014 but 1,000 head less than September 2015. The year-over-year decrease in yields for the month of October followed positive changes for all previous months in 2015.

### 1.2.1 Modern dairy farming

The recent evolution of the market for milking equipment has changed the daily routine work of the employees: we have moved it from the manual milking of the early twentieth century, the mechanical milking we know today, up to the new systems completely robotized (still present in very few reality)

Despite the mechanization now introduced, albeit with different modalities, in almost all herds, depending on the type of milking parlor, the work of the milker is still present as one of the most penalizing in the agricultural sector for reasons of ergonomic type (noise, humidity and air temperature), a social (two daily shifts at 12 hours and night work) as well as the widespread presence of a risk of biomechanical overload of the upper limbs.

The types of milking parlor available today can be divided into two categories: a milking individual and collective milking. In the first case (self-tandem) cows are housed in individual items are taken care of and independently of the other subjects in the room; in the second case the animals are treated for groups of size equal to the number of milking stations of a row (defined : “parallel” and “herringbone” milking parlor), or are housed in individual boxes but cared for in strict sequence ("carousel or rotary").

These centralized systems are composed of the actual milking equipment (vacuum pumps, milking units, milk pipeline, gathering systems and refrigeration of milk) and the containment systems and placement of the animals in the items, typically consisting of systems gates mobile driven by pneumatic and / or hydraulic.

These loose-housing parlor systems are used in the U.S. as well in Italian dairy industry. Here follows a brief description:

**Figure 18** Herringbone milking parlor

**<u>Herringbone parlors</u>**

Cows enter the herringbone parlor (**figure 18**) in groups and stand at an angle to the milking pit, so that only the udder part of the cow is exposed to the laborer. This layout reduces the distance between the udders significantly and saves walking time for the laborers between milking points.

Many variations of the fishbone parlor, sometimes called the 'para-bone', have been installed, which reduces the distance between cows with 760 mm and 860 mm. Standard fish-bone parlors vary in size from 4 to 20 milking points at each side of the pit. Fishbone parlors are suitable for dairies with 200 to 500 cows.

**Figure 19** Parallel milking parlor

**<u>Parallel parlors</u>**

In the parallel parlor (**figure 19**), cows stand on an elevated platform at a 90-degree angle facing away from the operating area. Access to the udder is between the rear legs, which reduces visibility of the front quarters and can make unit attachment and udder sanitation more difficult. A partitioning door that swings when a cow enters the milking stall opens the adjacent milking stall for the next cow. In most parlors, the gates overlap, to prevent the cows from entering the milking stall beforehand. As a cow enters the parlor, there is no milking stall available to enter, except the last one in the line.

**Figure 20** Rotary milking parlor

## Rotary parlor

In the rotating parlor (**figure 20**), cows are milked on a rotational, raised, circle shaped platform. There are many variations of this type of parlor, based on the way the cows stand on the platform. They can stand in tandem, fishbone or parallel formation, with their heads directed towards the inside or the outside of the platform. The most logical choice is the parallel-type with the heads of the cows directed inward, as this takes up the least space per cow. The laborers remain in the same position on the outside of the platform, while the cows move in rotation towards, them. The speed of the platform can be controlled to give the laborers sufficient time to prepare the cow and fit the claw piece.

The advantage of the rotary parlor is that the cow movement functions are largely automated, freeing the operators to tasks more directly associated with milking. Rotary parlors typically require three operators: one for unit attachment, one to detach units and/or apply post milking teat dip and one to tend to any problems occurring while cows are traveling around. This parlor type is not expandable and the capital cost is usually higher per stall than for non-moving parlors. Because of these characteristics, rotary parlors are best suited to larger herds (>1000 cows).

In the last 10 years average U.S. herd size has increased from 123 to 196 cows per farm in order to compete with the growing numbers of large-herd (1000-1500 cows) and mega-herd (1500+ cows) farms [155]. Conversely, within the European Union average herd size can vary from 3 to 141 cows per farm [156]. This is primarily because since three decades, milk production in the EU had been pre-established for each country, and historically each country it was not permitted to exceed that determined value until the quota system has expired on march 31th 2015.

### 1.2.2 Wrist –hand MSD in dairy farming

Among agricultural work activities, dairy farming is of particular interest in occupational medicine because of the variability of tasks and exposure to a variety of biomechanical risks. As for dairy workers, researchers have identified heavy lifting loads and repetitive motions contributing to adverse musculoskeletal effects on the lumbar spine, shoulders, necks, hands and wrists [157]

#### *1.2.2.1 Milking parlor tasks*

According to existing literature [158,159], the milking tasks requiring particular hand and wrist intensive efforts in terms of the repetitive physical exposures are:

1. Pre-dipping of the udder (**figure 21**): this subtask involves disinfection or cleaning of the teat before milking. This process reduces the bacteria, particularly those from the environment such as E.coli, very often present on the teat. The teats can be dipped in disinfectant using a dip cup or sprayed. Both methods are acceptable as long as the whole teat is covered. This task does not require the worker to perform significant physical effort, although wrist posture can be critical due to the repetitiveness of the task and the need of covering the entire teat with disinfectant.

2. Wiping / stripping phase (**figure 22**): The wiping task is normally performed in different moments. In some countries, like Italy, wiping and stripping (stimulation of the udders) phases are performed simultaneously, whilst they are separate phases in others. Using a dry towel to wipe-off and dry the teats thoroughly it is particularly important to get the entire teat and tip of the udder clean. The fore-stripping task (2-3 squirts of milk from each teat) is also important to check the presence of abnormal milk and stripping represents the best way to detect mastitis. In this phase, the worker strips each teat at least once in order to achieve the results just described above. Therefore, considering an average of 50 cows milked per hour, it is estimated that the workers perform this subtask at least 250 times per hour. The repetitiveness of this activity makes it one of the most critical factors in the overload of the upper limbs.
3. Attaching of the milking cluster (**figure 23**): After drying the teats, the milking cluster is attached to the cow's teats. This operation is very important because the risk of new infections depends on the percentage of air leaked during the attachment. After attachment, the unit is aligned in order to hang squarely on the udder with a slight forward pull. This phase appears to be the most physically demanding for the upper limbs of the workers since it requires the milker to insert the each of the four section cups of the cluster into a teat. This task involves repetitive flexion and pronation / supination of the wrists and it has been considered one of the most strenuous tasks [160], requiring approximately 10-15% (range 5-25%) of the maximum volunteer contraction (MVC) [126]. The effort mainly depends on the weight of the milking unit (estimated from 1.5 to 3.5 kg), therefore a significant reduction can be achieved using less heavy milking units [126] or providing the workers with support arm that reduce the load on the biceps [162].
4. Post-dipping of the teats: This task is similar to the pre-dipping task and serves to eliminate bacteria transferred onto the teat during the milking process. Post-milk teat disinfection can

be achieved by applying a suitable disinfectant to the teat immediately after every milking.

As with pre-dipping, teats can be dipped in disinfectant using a dip cup (bottle) or spray.

In each phase, also parlor design and anthropometric and bovimetric measures affect the levels of physical overload. [126] The three common milking systems used in Italy include the rotary, the parallel and the herringbone design systems (**see figures 21-23**).

**Figure 21** An Indian dairy worker performing the pre-dipping subtask in a parallel milking parlor; Lombardy region, Italy.

**Figure 22** An Italian milker performing the stripping/wiping subtask in a herringbone design milking parlor; Lombardy region, Italy.

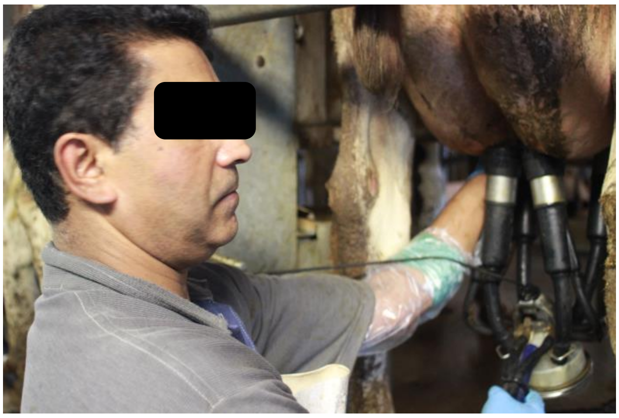


**Figure 23** An Indian milker performing the attaching phase in a rotary milking parlor; Lombardy region, Italy.

In each of the three parlor configurations, workers perform the same four primary milking tasks described above. Although workers may rotate from station to station or from cow to cow, it is evident that awkward postures, repeated exertions, velocity of wrist movements of flexion and extension, radial-ulnar deviation and dorsiflexion are the main biomechanical risks affecting the upper limbs. [86,162,123] The introduction of the new loose housing milking systems has increased hand dorsiflexion and repetitiveness [119] as well as static load but reduced muscular rest [164]. Industrialization has also brought about an increase of the time spent in milking activities and therefore the levels of workers' exposure to these risk factors [160].

### *1.2.2.2 The burden of occupational disease in dairy farming*

Among farming, dairy is of particular interest for occupational health because of the variability of tasks and exposure to several biomechanical risks, difficulties faced in performing risk assessment activities in the sector as well as in defining the real burden of occupational diseases due to different personal and occupational variables that must be considered. The increase of MSD reported in the last years in agriculture sector in Italy (INAIL , 2014) lead necessarily the physicians to consider the need of preventive strategies and thus to evaluate the complexity of the variables affecting the risk of developing MSD.

Kolstrup [157] used a modified version of the Standard Nordic Questionnaire to determine a high prevalence of MSDs among workers in shoulders, hands/wrist, and low back in Swedish small-herd dairies. These investigations examined broad categories of MSS and WRMSDs rather than specific disorders. Patil et al [165] examined the prevalence of carpal tunnel syndrome among workers in large-herd dairies and concluded that the prevalence of carpal tunnel syndrome was significantly higher among workers performing milking tasks than those in other areas of the dairy.

The main symptoms resulting from the above-mentioned exposures activities are tingling, numbness, pain and/or reduced muscle strength [155,166]. In some cases, symptoms are accompanied by evidence of entrapment of the median nerve at the level of the elbow and the wrist (Carpal Tunnel Syndrome) [85,165,167, 168 ]. In this light, median nerve seems to be the most sensitive target of the repetitive forceful handwork [75], but other soft tissues of the area may be affected [169].

Most of the available studies on workers' wrist and nerves have been conducted with ultrasound examination, which seems to be highly sensitive for detecting abnormalities, but unable to provide information regarding the severity of the changes [170]. For this reason, as mentioned before ultrasound approach must be accompanied by physical examination and symptom collection [171].

Available data suggest the existence of a significant health risk, but the information comes from very small study groups. Besides a systematic review of literature on musculoskeletal disorders in agriculture concluded that the spine is the most studied body region, followed by lower and upper extremities. This review highlighted the necessity to conduct studies focused on specific types of farming, physical exposures specific to the worker's tasks and specific body parts [172].

The main reasons for this situation are, from one side, the well-known poor access of rural workers to health surveillance at the workplace, and, from the other side, the fact that ultrasonography approach is still time consuming, not easy to conduct at the workplace, and therefore non-adequate for screening activities.

As highlighted in other studies, there is paucity of data describing standardized scanning methodology and standardized definitions of US pathologies [173]. Therefore, there is a growing need for additional studies specifically focused on defining a scan method able to allow the involvement of larger groups of workers and to perform routine health surveillance of workers at the workplace.

Besides, both in small and in large herd size loose housing dairy farms, it has been demonstrated that milking tasks represents very demanding activity [165] for hand and wrist as part of upper extremities in terms of repetitive motions [168, 174], pronation/supination of the wrists, milking units lifting [174,175], dorsiflexion and radial deviation [161, 175]. Physical workload is strongly influenced by parlor design [126,178] and both anthropometrics and bovimetrics characteristics [126]. The presence of several individual variables (age, BMI, co-presence of common disease such as arthrosis) affecting the wrist's vulnerability to strain makes very complicated performing a sound evaluation of biomechanical risk for this specific body district. Lastly, the continuous evolution of technology and workforce characteristics, typical of this sector, pose the challenge of defining tools adequate to face a continuous evolution of exposure characteristics and intensity [178]. It is evident that several indicators may be measured and assessed, and the specificity of the district to be evaluated makes is necessary to adopt an approach in which both qualitative and quantitative indicators are measured and an integrated evaluation is performed

Previous workload assessment studies among milking parlor workers have been conducted [168, 174, 126, 179] and many others concluded that the biomechanical risks may bring about a significant burden of disease in parlor workers [157, 180,181].

All those studies conducted in Europe as well in US were focusing on the correlation among body and dimensions and workplace [177] or investigating the extent of the physical strain and exertion as well as body kinematics of employees during specific subtasks [126]. Douphrate and Rosecrance [182] used sEMG to assess muscle force from the upper trapezius, anterior deltoid, and forearm flexors and extensors during a full shift of milking within a loose-housing dairy parlor. Amplitude probability distribution function [APDF], a common measure for average muscle activity [136], results revealed high peak loads in the anterior deltoid and forearm flexor muscles. Rosecrance and Douphrate [183] re-examined muscle activity in combination with joint positioning over the course of the full milking shift. Exposure variation analysis revealed a majority of the muscle contractions to be less than one second in duration and forceful. From postural analysis the authors determined that workers elevated their shoulder above 45 degrees for roughly 40% of the work shift. Forceful exertions and repetitive motions such as these, combined with awkward postures present an increased risk for MSDs.

Therefore since upper extremities biomechanical overload in milking parlor workers is affected by several aspects, Jacob et al. concluded in 2012 [126] that there is a need of studies that impact specific workload profile for the individual parlors operative. The lack of information regarding biomechanical risk of the wrist in milking parlors make complicated to define proper preventive measures bases on actually measured risks and the related burden of occupational disease. In this frame, it is evident the need of both refining tools adequate for performing a complete risk assessment and management and defining specific risk profiles for some main work and exposure scenarios. Studies that address the risk assessment of biomechanical overload of the wrist, contemplating physical workplace factors, personal variables as well as perceived stress are desirable. Finally, recent studies pointed out that for the health surveillance, especially in some areas as well as the one of biomechanical overload, the number of evaluation studies is small, so there is a need of studies with original data [141].

Preventing MSDs is a complicated challenge, and there is a need to develop research on intervention studies which improve our understanding of the efficacy of different prevention strategies and different implementation strategies that are usable in the workplace [184].

In this light, this research addresses a specific sector of muscle skeletal disorders, which is wrist. The risk of wrist work-related MSD due to biomechanical overload in milking parlor workers will be investigated, and prevention criteria for risk management will be proposed.

Additionally, as previously presented, the effects that milking has on upper extremity musculature has also been well documented in both geographies USA and Italy. Unfortunately, direct comparisons between European and U.S. milking systems have not been undertaken. Dairy systems are similar on both continents because using loose-housing dairy parlors is common. However, differences in herd size between the two regions greatly affect volume of work and task specialization [179], posing challenges in comparing small-herd and large-herd findings. To date, there are no reports in the peer-reviewed literature that quantify and compare muscle activity data gathered from large-herd, loose-housing parlor systems in the U.S. with muscle activity data collected from small-herd, Loose-housing parlor systems in Europe. The last aim of the present research (conducted in the U.S. state of Colorado and the Lombardy region of Italy) was to discern if there are differences between large and small-herd parlor systems with regards to muscle activity and muscular rest among milking workers.

## 2. Aims of the study

The objectives of the study were the followings:

a) define risk profile of biomechanical overload of the wrist due to repetitive strains in milking parlor workers;
b) define preventive criteria addressed at risk control in dairy activities;
c) Compare the levels of muscle activation in milking work between large herd operations and small herd operations.
d) estimate the possible effects on wrist structures exerted by the repetitive motions performed during milking activities through questionnaire, clinical tests and ultrasonography;
e) develop screening tools useful in the periodical health surveillance of dairy workers to detect s early stages signs of sufferance of the wrist;

## 3. Materials and Methods

This project has been carried out in 2013-2015 period. Data were collected and analyzed in Italy and USA (Colorado State). Since the complexity of the research aims, the project has been developed 4 studies, as follows: **1 pilot study**, mainly addressed at estimate the possible effects on wrist structures exerted by the repetitive motions performed during milking activities and 3 main studies, addressed, respectively at develop screening tools useful in the periodical health surveillance of dairy workers to detects early stages signs of sufferance of the wrist (**study 2**); define risk profile of biomechanical overload of the wrist due to repetitive strains in milking parlor workers and indicate preventive criteria addressed at risk control in dairy activities (**study 3**) and lastly verify if there are important differences between muscle activation profiles between large herd operations and small herd operations (**study 4**).

Since the necessity of a holistic approach, the activities have been carried out with the contribution of many expertise and a really wide working team.

The main collaborating expertise involved have been:

- A physiotherapist
- Medical doctors (occupational medicine, morphology, imaging diagnostics)
- a biomedical engineer
- an agricultural engineer
- technicians of prevention

The four studies are self-standing, but strongly linked and synergic. Thus, each of the following chapter represent a specific study developed during the PHD path. They include a description of the materials and methods adopted in order to achieve the mentioned aims and the relative results, discussion and conclusions.

# 4. Study 1: Assessing the effects of biomechanical overload on dairy parlor workers' wrist: definition of a study approach and preliminary results

## 4.1 Materials and methods

### 4.1.1 Population

The pilot study was conducted on a group of 14 male dairy parlor workers selected among the enterprises being provided with occupational health surveillance by the International Centre for Rural Health of the University Hospital San Paolo of Milan, a World Health Organization Collaborating Centre. Twenty-two male healthy subjects were selected as a control group, paired with the exposed for gender, age and ethnicity. None of the control subjects had ever been engaged in agricultural activities or jobs requiring manual handling of heavy loads or repetitive motions. In particular, their jobs were pony express, florist, cobbler. Three subjects were unemployed.

### 4.1.2 Data Collection Protocol

The experimental approach, approved by the ethical committee of the University Hospital San Paolo, was based on three components: 1) the identification of worker's symptoms through the administration of a questionnaire, 2) ultrasound imaging (ultrasonography) of the wrist region performed with portable ultrasound instrumentation, and 3) a physical examination of the upper limb including standardized clinical tests. Before participation, the involved subjects have been informed about the approach and the aims of the study and firmed an informed consent.

All the following activities were conducted at the workers' workplace, in rooms made available by the employers and declared adequate to the study by the research group.

Since most of the milkers were migrants, with a low educational level, questionnaire was completed with a graphic representation of a human body on which the workers were asked to indicate the body areas where symptoms such as pain, tingling/numbness, weakness, night symptoms were present. In addition to symptoms, the following information was collected from all participants:

nationality, gender, age, education level, occupational history, body weight, height, exercise habits, handedness, duration of present job, hours worked per day, and the presence of manual materials handling tasks during the work shift. We also asked the milkers to estimate the number of animals milked per day and about the type of milking system (rotary, parallel or herringbone) and milking cluster characteristics they used during their work-shift.

The ultrasonography (US) examination was performed by a sonographer according to the European Society of Musculoskeletal Radiology's protocol (ESSR) [185, 186], with the exam of more than 20 putative acoustic windows in both wrists (**Table 9**). The ultrasonography equipment (Venue Scan, Venue 40, GE Healthcare®) allowed the researchers to store the exam for further evaluation and discussion with other hospital experts in the final evaluation of all cases.

Wrist was investigated through the determination of the following parameters: US texture, shape, situs, range and pattern of motion. For the classification of the ultrasound study results, we adopted the grading system proposed by Yoon et Al. [187] and by Wakefield et al. [173], with minor modifications. In particular, we decided that the best way to divide the results in the frame of a preventive approach is giving a particular attention to preclinical and very early changes, fundamental for secondary prevention. Therefore, we are based on the identification of two categories, that is 0=normal/expected and 1=abnormal. However, Since a dichotomous classification does not discern the severity of changes in the ultrasound signal detected, preventing created the following classification criteria were for nerve and tendon findings:

- Tendons: category 2: a) a discontinuity in the ultrasound signal of the texture and a permanent dislocation. Category 1: a) heterogeneity of the ultrasound signal in the texture, b) not permanent dislocation c) increased anechoic signal of the synovial space. Category 0: a) normal.
- Median nerve category 2: a) Immobility with changes of shape and increase of area hypoechoic and altered fibrillary pattern when  median cross sectional area is major than 15

mm$^2$ in the median nerve . Category 1: a) Increase of area hypoechoic and altered fibrillary pattern when median cross sectional area is between 10 and 15 mm$^2$ in the median nerve, b)immobility without changes of shape. Category 0 are : a) normal.

All milkers and controls underwent a clinical examination of the upper limbs, performed by an occupational health physician. The clinical exam included an evaluation of symmetrical posture of the clavicles, hypersensitivity to palpation, hyperextension and hyper flexion of the fingers; Finkelstein test, Phalen's maneuver; Tinel's sign, radial and ulnar reflexes, elbow, wrist, finger range of motion (ROM), and sensitivity to an upper limb tension test of the median nerve [188]. Since most of available data suggest an impairment of median nerve, we completed the physical examination of the workers with the pinch-holding-up activity (PHUA) test [189]. We chose this test, among the others available to the purpose, because pinching activity seems to be particularly significant in milking tasks. Only one test was applied among the different tests available because of the need of defining a screening procedure, to be easily and rapidly performed at the workplace. Evaluation was performed asking the workers to lift with the pulps of thumb and index finger to 5 cm above of a small metal clip placed on a plain top, for 5 seconds. Results were dichotomously classified (0= normal; 1 = reduced gripping capacity).

| US dorsal scans | |
|---|---|
| **Distal radioulnar joint** | |
| **I compartment** | Retinaculum |
| | Abductor pollicis longus tendon |
| | Extensor pollicis brevis tendon |
| **II compartment** | Retinaculum |
| | **Extensor carpi radialis longus tendon** |
| | **Extensor carpi radialis brevis tendon** |
| **III compartment** | Retinaculum |
| | Extensor pollicis longus tendon |
| **IV compartment** | Retinaculum |
| | Extensor digitorum communis tendons |
| | Extensor indicis proprius tendon |
| **V compartment** | Retinaculum |
| | Extensor digiti quinti proprius tendon |
| **VI compartment** | Retinaculum |
| | Extensor carpi ulnaris tendon |
| **Radiocarpal/midcarpal joint** | |
| **US ventral scans** | |
| **I compartment** | Flexor carpi radialis tendon |
| **II compartment Carpal tunnel** | Retinaculum |
| | Median nerve |
| | Flexor pollicis longus tendon |
| | Flexor digitorum superficialis tendons |
| **III compartment** | Guyon tunnel |
| **IV compartment** | Flexor carpi ulnaris tendon |

**Table 9** The acoustic windows considered in the study

The majority of the variables from the questionnaire and clinical exams were dichotomous and classified as either absent or present.

Reference collection have been updated. To this aim, a search string specifically aimed at agriculture has been used, with minor additions or changes [190].

### 4.1.3 Statistical Analysis

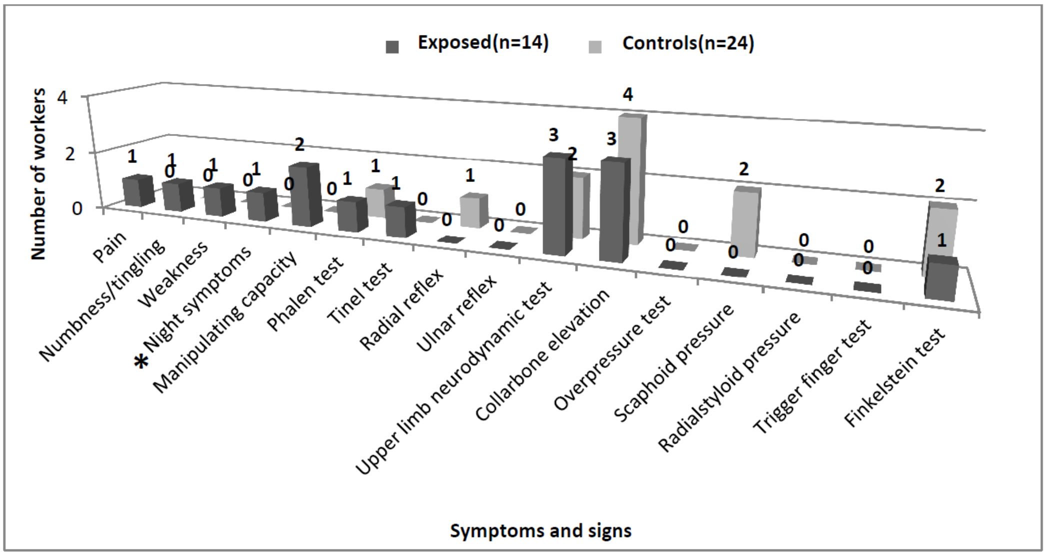
Statistical analyses were performed with SPSS PC version 22. Differences between groups (milkers and controls) were assessed with Chi Square and Fisher tests with statistical significance set at $p \leq 0.05$.

## 4.2 Results and conclusions

In this pilot study, we studied a group of 14 dairy parlors workers and 22 controls. There were no significant differences between exposed and controls for the potential confounding factors of age, gender, and ethnicity. The milkers were engaged in their work activities for periods ranging from 0.5 to 40 years (median = 15.5 years)

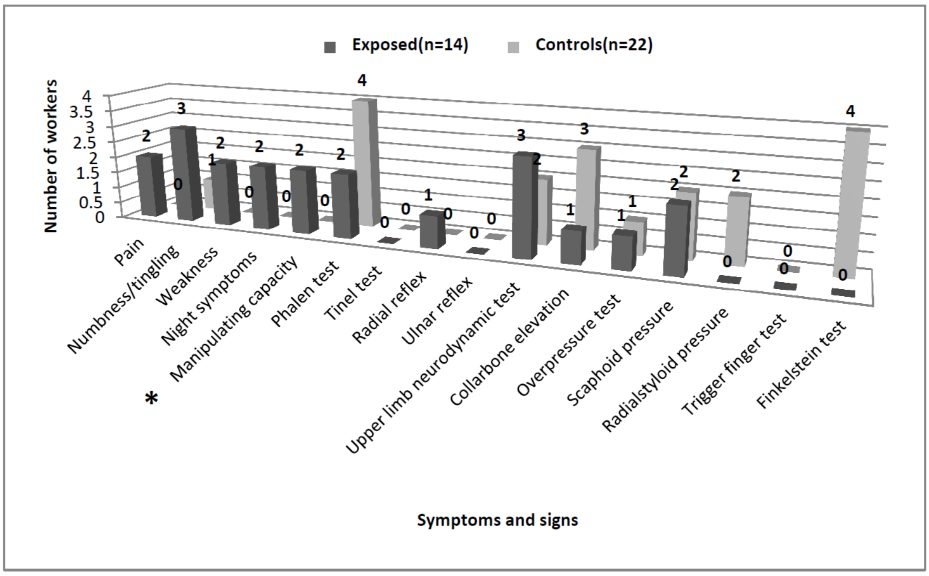
***Symptoms***

Symptom histories indicated that a higher proportion of dairy parlors workers versus controls reported wrist pain (3/14 versus 0/24 for controls), numbness and/or tingling in the fingers (4/14 versus 1/24), weakness in the hand (3/14 versus 0/24), nocturnal pain or paresthesia (3/14 versus 0/24). None of the proportional differences in symptoms were statistically significant between the two groups. The lack of statistical significance may have been at least partially due to the small sample size of the study groups. The physical examinations revealed that a higher and statistically significant ($p < 0.05$) proportion of milkers suffered a reduction in the pinching capacity compared to controls, whilst the clinical testing failed to show any difference between the groups (**Figures 24 and 25** ).




* p<0.005

**Figure 24** Signs and symptoms of wrist impairment between the study groups – left hand




* p<0.005

**Figure 25** Signs and symptoms of wrist impairment between the study groups – right hand

### *Ultrasonography*

In **table 10** are summarized the musculoskeletal and neurologic ultrasonography findings evidencing statistically significant differences between exposed and controls.

| Groups | | | | Milkers | | | Controls | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Biomechanical compartments** | **Structures** | **Compartments** | **Side** | **0** | **1** | **2** | **0** | **1** | **2** | **p** |
| Articulation compartment | Radiocarpal & Midcarapal joints | RC & MC J | L | 11 | 3 | 0 | 24 | 0 | 0 | 0,020 |
| | Radiocarpal & Midcarapal joints | RC & MC J | R | 8 | 6 | 0 | 22 | 2 | 0 | 0,013 |
| Extensor compartment | Extensor carpi ulnaris tendon | ECU | L | 7 | 5 | 2 | 24 | 0 | 0 | 0,000 |
| | Extensor carpi ulnaris tendon | ECU | R | 8 | 6 | 0 | 22 | 2 | 0 | 0,013 |
| Flexor compartments | Median nerve | MN | L | 6 | 6 | 2 | 24 | 0 | 0 | 0,000 |
| | Median nerve | MN | R | 8 | 4 | 2 | 23 | 1 | 0 | 0,003 |

**Table 10** Muscleskeletal and neurological ultrasonography abnormalities

Legenda
Morpho-functional compartments with abnormalities
0=normal/expected, 1=abnormal/unexpected, 2=evidence of frank alteration
RC-MCJ= Radiocarpal-Mid carpal joint
ECU=Extensor carpi ulnaris muscle, MN=Median nerve, M= Milkers, C= Controls

The main findings were:

- increase of the synovial space at the Radiocarpal & Mid carpal joints **L**eft (p=0,020), **R**ight side (p=0,013)
- echotexture alterations such as fibrillary pattern disorganization, intra-tendon gaps, permanent and not permanent dislocation at the extensor carpi ulnaris tendon: L side (p=0,00) and Right side (0,013). As for the degree 2 lesions, we observed dislocations (2 L) and ruptures (2 L) in the ECU tendon.(**figures 26 and 27** respectively )
- increase of the transversal cross sectional area (**figure 28**) as compared with a normal nerve (**figure 29**), hypoechoic and altered fibrillary pattern and changes of shape and mobility at the median nerve left side (0,000) and right side (p=0,003). As for the degree 2 lesions, we observed immobility and median cross sectional area major than 15 $mm^2$ in the median nerve (2L and 2R).

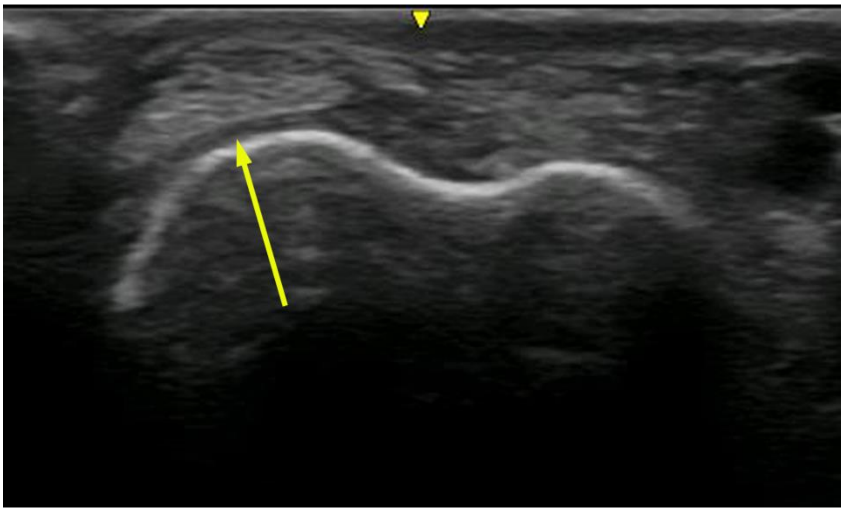


**Figure 26** Dislocations in the ECU tendon

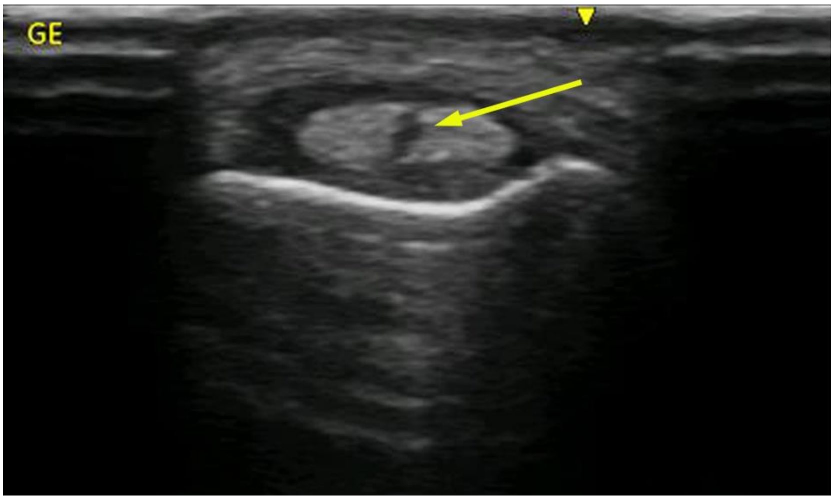



**Figure 27** Ruptures(2 L) in the ECU tendon

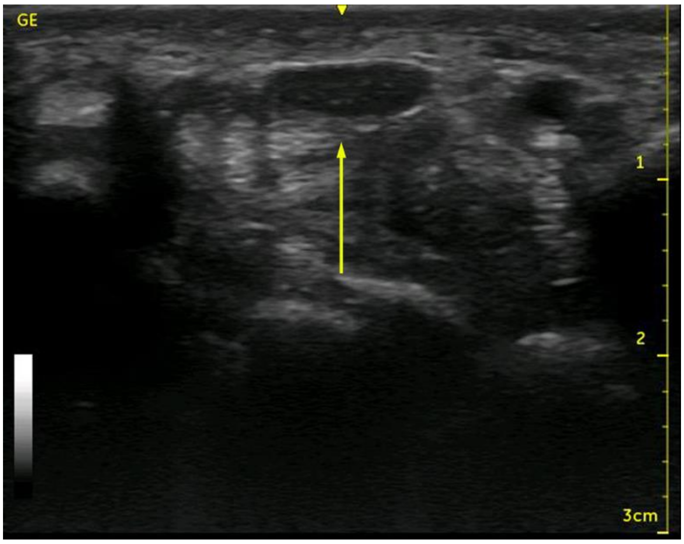



**Figure 28** Median Nerve :increase of the transversal cross sectional area . Exposed subject.

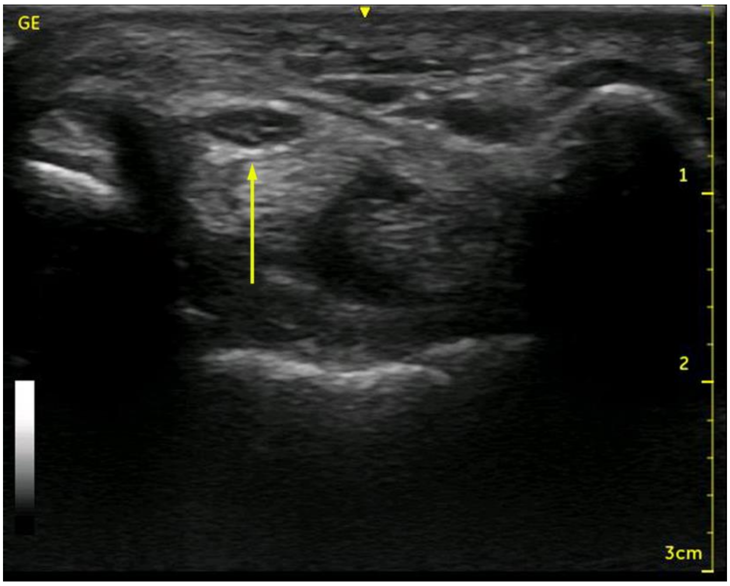



**Figure 29** Median Nerve : Normal Transversal cross sectional area

Our data are in agreement with literature limbs [85, 162, 163] and suggest that the median nerve tract in the carpal tunnel and the extensor carpi ulnaris tendon are the components most vulnerable to the biomechanical overload associated with milking tasks. Moreover, four milkers present rupture (2) or dislocation (2) of the extensor carpi ulnaris tendon. The reduction of wrist stability brings about an alteration in mobility of the median nerve, thus increasing the wrist sensitivity to biomechanical overload because of a reduced efficiency of the painful limb motions [191]. The reduced muscular and ligamentous stabilizing action increased stress that may affect the carpal nerve segments with consequences on endoneural blood flow [192]. As a consequence, gripping capacity can be affected and, according to Iida et Al [193 ], has the potential of contributing to nerve lesion and arthritis. Overall, the main findings of the present study include an increased incidence of changes of median nerve in the upper limb and musculoskeletal disturbances primarily at the distal tendon of the extensor carpi ulnaris in workers engaged in milking tasks.

The statistically significant reduction in the fine hand manipulating capacity, assessed by the pinching test, might be consequent to both median nerve and tendon impairment. These data confirm that wrist may be target of the biomechanical risk present in milking activities and suggest the need of further research on matter. Another important finding was that ultrasonography showed alterations of variable level of severity even in presence of very mild symptoms or in fully asymptomatic subjects. This was the case of the increase of the median nerve cross sectional area (**figure 28**) and tendon's dislocation (**figure 26**) which have been observed in subjects who did not report any major symptom of wrist impairment. This might suggest that ultrasound assessment may represent a valid tool in the identification of occupational diseases in a very early stage, making it a possible secondary prevention strategy of neurovascular and musculoskeletal disorders. Since the lesions we observed were present only in 2 acoustic windows, that are the extensor compartment-6 and the flexor compartment-3 (carpal canal), we can speculate that these windows have the greatest positive predictive value for detecting wrist diseases in the conditions of exposure considered.

Therefore, the main outcome of this study has been the creation of the possibility of simplifying the ultrasonography approach to dairy parlors workers' wrists. In fact, the definition of two acoustic windows and the use of a portable device might allow to overcome the limitations existing at the conduction "in field" studies that are the time required to perform ultrasonography to multiple acoustic windows and the challenge of exam conduction at the workers' workplace, needed in all occupational health screening.

In particular, the approach briefly consists in the administration of a symptoms questionnaire, a clinical test completed with the pinch-holding-up activity (PHUA) test and ultrasound evaluation of the two putative windows considered as the most predictive for the detection of wrist disorders (extensor compartment-6 and flexor compartment-3). Of course, we are well aware that the small size of the study groups may have affected our results that, even though, consistent with the results of similar studies, need to be confirmed on larger population samples.

# 5. Study 2 : Biomechanical overload effects on the wrist of Italian dairy parlors workers : a risk assessment screening tool

## 5.1 Materials and methods

### 5.1.1 Population

The study involved forty dairy parlors workers. Milking activity in Italy is mostly a male prerogative, for this reason and in order to eliminate any gender specific variations the research included male workers only. The 21 farms involved were representative of the milking parlors system adopted in Italy: herringbone (22), parallel (8), rotatory (10) systems. The subjects were recruited from the lists of workers in the health surveillance program of the San Paolo Hospital - University of Milan. Selection criteria were: having at least 3 years of working activity experience as dairy parlor workers, not have any musculoskeletal surgery or upper limb related diagnosis since 3 years before the survey started.

Before participation, the involved workers have been informed about the approach and the aims of the study and firmed an informed consent.

### 5.1.2 Data collection protocol

The study protocol consisted in: 1) identification of worker's symptoms through the administration of a questionnaire, 2) ultrasound imaging of the wrist performed with portable ultrasound device, and 3) physical examination of the upper limbs. The levels of concordance between questionnaire results and clinical and ultrasound evidences has been evaluated.

### *The questionnaire*

The questionnaire administered by the researchers contemplated a demographic and a specific symptom sections. Information about age, nationality, stature, weight, sport, work history (other current job and job performed in the past) has been collected. Since most of the milkers were migrants, the symptoms section of the questionnaire was completed with a graphic representation of a human hand-wrist on which the workers were asked to indicate the areas where symptoms such as tingling/numbness, burn, weakness, pain were present. (**Appendix 1**).

They were also asked to specify the severity of the symptoms on a Visual Analogic Scale from minimum to maximum. The subject's evaluation was translated in a linear scale were 0 was corresponding to absence of symptoms and 10 corresponding to the maximum experience of symptoms. The questionnaire also collected information about the symptoms: onset time (when was the first time the symptoms appeared), the qualitative aspects of the symptoms (if the symptoms were constant or intermittent), when was the part of the day they mostly appear) and any work limitation present (**figure 29**).

None of the workers declared his self-affected by weakness, thus we didn't consider weakness in the decisional making tree.

### *Clinical test*

All workers underwent to ULNT 2a (Upper Limb Neurodynamic Test) modified by a physiotherapist [194] in order to be performed in standing position. This is a provocative test because it is able to induce Median nerve tension. The test results were classified in dichotomous categories: 0=negative, 1=positive. We included in category 0 all the negative tests and in category 1 all the positive neural.

***Ultrasonography***

The ultrasonography (US) examination was performed by a sonographer according to part of the European Society of Musculoskeletal Radiology's criteria (ESSR). The sonographer collected a static image of the carpal tunnel at the level of the semilunar bone in transverse plane and a video at the same position during the flexion-extension movement of the fingers. This investigation was performed on both the wrist. The ultrasonography equipment (Venue Scan, Venue 40, GE Healthcare®) allowed the researchers to store the exam for further evaluation and discussion with other hospital experts in the final evaluation of all cases. Based on the evaluation of the static image, a quantitative measurement of the cross sectional area of the Median nerve has been done. Based on the evaluation of the video, a qualitative evaluation of the mobility of the Median nerve has been obtained. Because of the complexity of the present study, we decided at the moment to use for the classification of the subjects only the median nerve CSA parameter.

According to literature [185, 186] the cross sectional area (CSA) is classified in 3 classes: normal if <10 $mm^2$, sign of sufferance if between 10 $mm^2$ and 14 $mm^2$ and sign of lesion if >14 $mm^2$. Therefore, in line with Sernik et al.[195], during the fingers movements the median nerve has a physiological radio-ulnar translation underneath the carpal tunnel ligament.

Since our study aimed to create a screening tool, we use the ultrasound investigation as one of the indicator of subject health condition. In category 1 were classified all the workers considered "at risk" at least for one wrist (CSA >14 $mm^2$), while all the other workers were classified in category 0.

### 5.1.3 Statistical analysis

Statistical analysis were performed with statistical package SAS (SAS Institute Inc. 2008. SAS/stator 9.2 user's guide. Cary, NC: SAS Institute, inc). Chi Square with statistical significance set at $p \leq 0.05$ was used in order to validate the questionnaire.

## 5.2 Results and discussion

### *Study population*

The subjects' average age was 43 years old, with average of 13 years of work experience as dairy parlor workers. Subjects were of mixed ethnic backgrounds: 37% (15 subjects) of the study population were from European countries while 62.50% (25 subjects) were not European including Indian (20), Tunisian (2), Pakistani (2), and Egyptian (2). It is not unusual to find Indians employed in dairy farms in Italy [196]. Besides, most of the workers involved in the study (90%) didn't had any other job at the time of the survey, the others were involved in multitasking activities in the dairy farm and only one declared that was working in industry. The 30% (12 subjects) of the population under study declared they don't have other previous work experience in other sector, while 20% (8 subjects) was animal breeder and thus pretty often involved in other dairy activities such as fecundation. The 17.5% (7) of the subjects were mostly performing other jobs (i.g. carpenter, taxi driver, warehouseman, trader), or was working in building construction sector (6 workers representing the 15% of the subjects), while 4 of them (10%) were employed in industry.

### *The questionnaire*

A decision making layout has been used to process part of the information collected with the questionnaire (**figure 30)**.

Only the information about the type of symptoms (numbness, tingling and pain), onset time (when was the last time it appeared) and the day/night time onset were considered to classify the subject's condition in 4 patterns:

- Negative (**Pattern 0**): were classified all the workers who didn't declare any of the symptoms contemplated in the questionnaire;
- Uncertain (**Pattern 1**): were classified all the workers positive to numbness/tingling, burning and pain.
- Positive to not neural syndrome (**patter 2**): a) all the workers positive to pain symptoms only, if appeared in the last two weeks; b) all the workers positive to numbness/tingling and pain; c) all the workers positive to numbness/tingling only; d) all the workers positive to burning symptoms only; e) all the workers positive to burning symptoms and pain;
- Positive to neural syndrome (**Pattern 3**) were classified all the workers positive to numbness/tingling and burning symptoms, if they were affected by them in the previous last two weeks and if the symptoms were present during the night or during the working/resting time.

Apparently, in the clinical practice, seems there is not an afford to discriminate the pain in mechanical or neuropathic. Thus, in our study when worker declared pain, in presence of other specific neuropathic symptoms (e.g. numbness, tingling, nocturnal) was classified as pattern 2 (positive to not neural syndrome), otherwise he was classified as pattern 3 (Positive to neural syndrome).

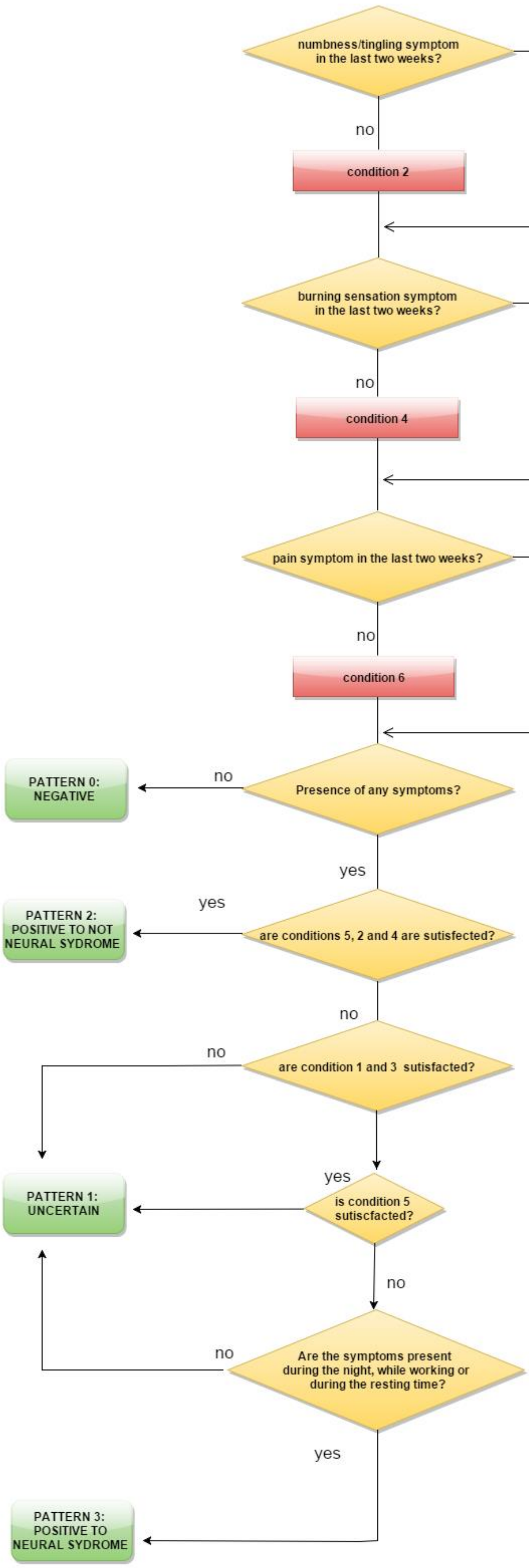



**Figure 30** Decision making flow chart for the symptoms section of the questionnaire

According with this classification, 30 subjects were negative to any of the symptom (pattern 0), 8 were classified as uncertain (pattern 1), 1 was positive to not neural syndrome (pattern 2), and 1 was positive to neural syndrome (pattern 3). (**Table 11**)

| Pattern | Subjects |
|---|---|
| **0 Negative** | 30(75%) |
| **1 Uncertain** | 8(20%) |
| **2 Positive to not neural syndrome** | 1(2.5%) |
| **3 Positive to Neural Syndrome** | 1(2.5%) |
| **Total** | 40 |

**Table 11** Workers Pattern based on the symptoms questionnaire results.

### 3.3 ***The questionnaire validation***

In order to validate the questionnaire the symptoms data were compared with the ultrasound and clinical tests investigation data. To date, all the subjects included in pattern 1, 2 and 3 of the questionnaire were considered positive to the neural dysfunction, all the others were considered negative.

If compared with the ultrasound imaging data, the questionnaire seems to have a specificity of 81% and a sensitivity of 100%. (**Table 12**)

| | | Ultrasound | | |
|---|---|---|---|---|
| | | Positive | Negative | Total |
| **Questionnaire** | Positive | 3(100%) | 7(18,92%) | 10 |
| | Negative | 0 | 30(81,08) | 30 |
| | Total | 3 | 37 | 40 |

**Table 12** Symptoms questionnaire results compared with ultrasound imaging**. (p=0.00018)**

Statistical significant differences among the workers were founded only for the nationality (p=0.02).

On the other side, if compared with the clinical test, the questionnaire has a specificity of 70.73% and a sensitivity of 25%. (**Table 13**) There were not statistical significant difference among the workers for the main demographic data collected.

| | | Clinical test | | |
|---|---|---|---|---|
| | | Positive | Negative | Total |
| **Questionnaire** | Positive | 2(25%) | 8(29.63%) | 10 |
| | Negative | 6(75%) | 19(70.73%) | 25 |
| | Total | 8 | 27 | 35 |

**Table 13. Symptoms questionnaire results compared with clinical test. (p=0.79990)**

Besides we even compared the results from the three screening tools. As shown in **table 4** Chi-square analysis shown no statistical significant differences among the 3 tools used to assess any sign of neuro-musculoskeletal disorders in dairy parlor workers. (p=0.13)

The 47.5% (19 subjects) of the workers recruited were negative to any sign of sufferance of the wrist, while 40% (16) where positive at least to one of the 3 screening tools.

The 12.5% percent (5 workers) of the sample couldn't be evaluated since the clinical test has been not administered to them because the conditions of the subjects were not appropriate.

The 3 workers declared the presence of symptoms as well: two were in the classified in the pattern 1 (uncertain) while 1 was positive to neural syndrome (pattern 3).

Moreover the questionnaire has shown an high percentage of specificity (82.15%) and sensibility (45.45%) (**Table 14**) if compared with both the clinical investigation outcomes (clinical test and ultrasound). (Predictive value =5/10)

| | | **Clinical Investigation protocol** | | Total |
|---|---|---|---|---|
| | | **Positive** | **Negative** | |
| **Questionnaire** | **Positive** | **5(45,45)** | **5(17,85)** | **10** |
| | **Negative** | **6(54,55)** | **24(82,15%)** | **30** |
| | **Total** | **11** | **28** | **40** |

**Table 14** Comparison between positive to questionnaire with positive to the clinical test and ultrasound.

Among the subjects positive to at least one of the two clinical investigation protocol (clinical test and ultrasound), three were positive to the ultrasound investigation and thus reported changes of the anatomical structures. Here followings examples of the detected morphological alterations.

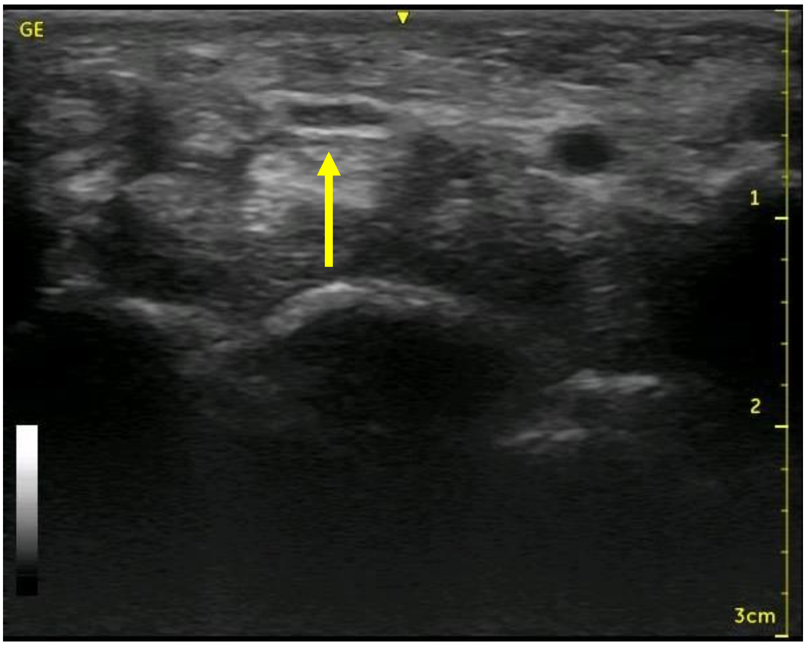



**Figure 31** Proximal carpal tunnel at the semilunar bone level. Short axis 12-5 MHz US Image. Arrow: normal Median nerve.

Anatomically, at the distal forearm, the median nerve courses between the flexor digitorum profundus and the flexor digitorum superficialis muscles. At the wrist it enters in an osteofibrous structure called carpal tunnel. In the tunnel, the Median nerve runs superficially to the tendons of the fingers flexors muscle and underneath the carpal tunnel ligament. The nerve has an oval cross section shape at the entering of this tunnel and tends to become flattened as it progress distally. (**figure 31**)

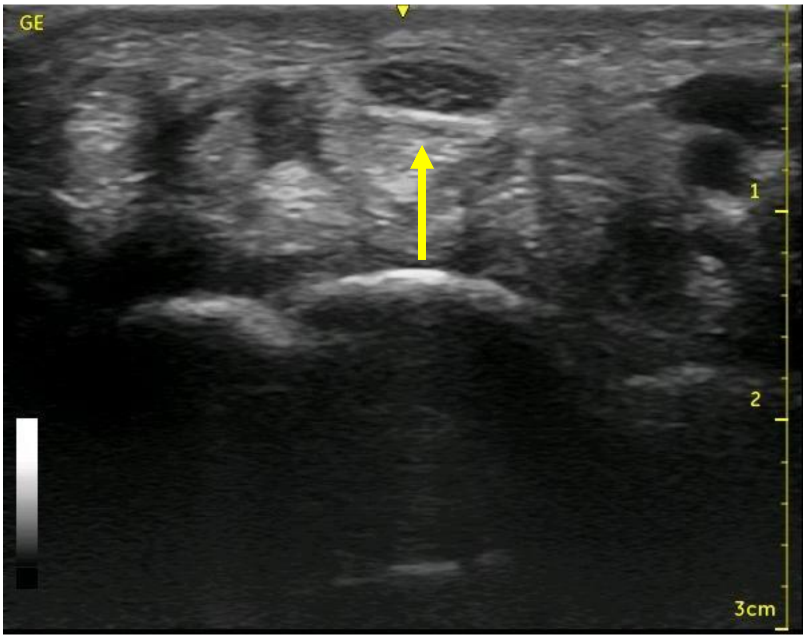



**Figure 32**. Proximal carpal tunnel (at the semilunar bone level). Enlargement of the Median nerve CSA (15. 5 $mm^2$), hypoechoic changes and alteration of the fascicular pattern. Short Axis 12-5 MHz US Image

In the carpal tunnel syndrome the US findings are changes in shape and echotexture of the Median nerve and alterations in the soft-tissue structures within the tunnel. When, the Median nerve is compressed in the carpal tunnel, it appears swallen and with an aumented CSA at the proximal tunnel [185,186]. Therefore, ultrasound scanning shows an hypoechoic Median nerve with alteration of the normal fascicuar pattern [197] as the one shown in **figure 32**.

Recent articles seems to confirm that sonography using cross sectional area of the Median nerve could give complementary results [59] and some others have suggested that among others ultrasound may have utility in the diagnosis of CTS [170, 171]. The present study confirms that ultrasound can be definitely useful for the identification of the wrist sign of alteration and give complementary information to the identification of wrist MSD. Therefore, the portable ultrasound tool used in the present study allowed to overcome the limits pretty often posed from the need to perform screening tools in the field, as requires in occupational medicine.

The Upper limb neuro-musculoskeletal system is a full evolved anatomic system and its “functional homeostasis” is necessary for man to perform even the most complex activities as the ones the milking activity requires. Subjects, environmental and working factors represent possible causes of alteration of the system which by itself has a very good capacity of adaptation and self-repair resources. A broken balance brings about the condition of illness.

The condition of illness can be reversible (as described in study 1). During the acute phase, signs of distress usually arise. However if no intervention in order to bring back the system to the homeostasis are not adopted, lesions are present.

Consequently it is necessary to observe the situation from different points of view using different tools at the same time. In the occupational setting, several case definitions for UL-WRMSDs, based on different combinations of symptoms, physical examination findings and instrumental test results, have been proposed and published in the literature. Previous studies suggested MSD symptoms are intermittent and episodic, especially in the early stages, thus symptoms report may not correspond to defined clinical syndromes [198, 199]. Besides, under-reporting of pain, when physical signs were present has been described by other researches [78, 89]. These situations were interpreted as being two to differences in pain thresholds, and work-related psychosocial factors including job security and labor relations with employers and co-workers [200,201,202]. Thus in line with Bonfiglioli et al [203] we agree that case definitions based on a combination of clinical history and instrumental findings has to be preferred and that this multiple screening evaluation has to be performed at the same time. Thus, the information gained by different tools need to be categorized in order to make the results comparable among them. Our study offers an algorithm that establishes different patterns for the subject, based on the pathogenetic causes. (**figure 30**) The high percentage of specificity (82% ) obtained by the questionnaire, when compared with other screening tools (clinical test and ultrasound) demonstrated is potentiality to detect the subject “at risk”.

## 5.3 Conclusions

The Questionnaire proposed has shown a high percentage (82%) of specificity if compared with ultrasound and clinical tests, thus it can be considered as a good screening and monitoring tool for the health surveillance program. Since both symptoms and instrumental findings can be affected by several variables such as exposure, individual factors, criteria used for data collection and time of examination in relation to work shift [203], in case of positive questionnaire there should be the possibility to immediately administer other screening tools (e.g. ultrasound).

Furthermore, the questionnaire was able to classify the subjects, based on the pathogenetic causes of the wrist MSDs. Future researches should focus on the classification of other screening tools results, based on pathogenetic causes.

## 5.4 Limitations

Our study has limitations. The questionnaire has a specificity of the 82%, thus it should be improved to overcome the uncertain situations. Besides, in order to classify the subjects based on the pathogenetic causes, specific parameters for the clinical test and the ultrasound should be identified.

# 6. Study 3: Risk profiles of biomechanical overload of the wrist in a sample of milking parlor workers.

## 6.1 Material and methods

### 6.1.1 Population

This study was carried out during the spring of 2014 on twenty one small-herd dairy enterprises located in Italy (Lombardy region) representative of the three main type of milking parlors adopted in Italy: herringbone (13, 22 workers), parallel (5, 8 workers), rotary (3, 10 workers) systems.

### 6.1.2 Data collection Protocol

The experimental protocol was approved by the ethical committee of the University Hospital San Paolo. Before the beginning of the study, the forty male parlor workers involved were informed about aims and methods of the project and signed their informed consent. Eligibility criteria were to have a least 3 years of experience in parlor and not having undergone any wrist surgery in the last three years.

The study started with a broad interview of the participants addressed at collecting personal and occupational information about workers and their work environment. To this aim, a specific data collection sheet (**Appendix 2**) was prepared. With this tool, we collected data on nationality, age, education level, occupational history, exercise habits and handedness, as well as the following anthropometric measurements: functional overhead reach, stature, functional stature, eye height, shoulder height (acromial), forward functional reach, waist height, grip breadth, inside diameter, body weight, BMI. ( **Appendix 3**)

Also detailed information on Milking parlor characteristics, environmental parameters, work organization was collected.

### *Posture Evaluation*

Workers were followed by our research group for the first hour of the working activity (mean 1,15' hours) and Strain Index values of the dominant hand were collected in order to determine the individual risk profiles. In particular, a wrist-hand strain analysis (S.I.) of all workers dominant hand has been carried out in the field by observers trained ad hoc with the Strain Index Method [101] . A specific Strain Index score was assigned for each single subtask the workers were used to perform during the milking activity (pre dipping, wiping/stripping, attaching, post dipping ). An average of the score assigned has been calculated in order to get an overall SI score for the workers dominant hand. The scores obtained were classified as following:

- S.I.>7 : risk situation
- 5<S.I. <6.99: uncertain risk
- S.I.<5 : no risk

### *Surface Electromyography*

After the collection of these data, workers underwent a clinical and Surface Electromyography examination.

Electromyography evaluation was conducted with the Biometrics Data LOG (Biometrics, England). Muscle activity was collected from the upper trapezius (UT), anterior deltoid (AD), long head of the biceps brachii (BB), wrist flexors (WF) and wrist extensors (WE) with a sampling frequency of 1000 Hz. Bipolar electrodes (Biometrics, LTD) were located on the skin directly over the midsection of the belly of each muscle of the dominant arm in the appropriate place individuate following [204] protocol (**figure 33**). One disposable reference electrode was placed on the contralateral clavicle. In order to minimize movement artifact. The electrode placement was completed with Hypafix medical tape (Hamburg, Germany) placed over the electrode holding it place.

Before the functional maximum voluntary contractions (fMVC) assessment, a 30 “ baseline resting sEMG signal was collected. *Functional Maximum Voluntary Contraction (fMVC)* completed the functional evaluation. fMVC procedures to obtain functional maximum contractions for the muscles UT, AD, BB, WF, and WE were performed. A minimum of three fMVC trials, observing 1 minute rest periods, were administered for each subject for each muscle. Once each trial was completed a three second RMS maximum was calculated. Covariance was calculated trough the mean and standard deviation determination., additional trials were conducted with a maximum of five total trials If the covariance was above 15% for the three fMVC trials.

Functional MVCs for the AD and UT were calculated following the procedures established by Boettcher, Ginn, and Cathers [205] . The UT fMVC was obtained using the "empty can" method [205]. Finally, WF and the WE fMVCs were obtained simultaneously through a co-contraction with the use of a dynamometer (Biometrics G100, England). Each subject was asked to to grip the dynamometer and keep the elbow in 90 degrees of flexion. The dynamometer grip was adjustable to the hand size of each subject. sEMG data were collected for the first hour of milking activity.(**Appendix 4**)

***Rating of perceived exertion***

The study was completed by the use of the Borg scale to determine the correlation between workers’ and observers perceived exertion when performing the S.I. evaluation. In particular, effort intensity was rated by the subjects through the use of the Borg Scale [206] of Rating Perceived Exertion (rating between “none at all”= 0 and “extremely strong effort”=10 points). The scale was presented to the workers only once after the first hour of shift, Subjects were asked to estimate the perceived physical exertion while performing each of the 4 subtasks of the milking activity(pre dipping, wiping/stripping, attaching, post dipping) . The study allowed to investigate any.

### 6.1.3 Statistical analysis

Statistical analysis were performed with statistical package SAS ( SAS Institute Inc. 2008. SAS/stator 9.2 user's guide. Cary, NC: SAS Institute, inc).

A multi correspondence analysis (MCA) was used to define the contribution of each variable collected with the questionnaire in the phase 1 of the study to the definition of the main risk determinants. Considering the main risk determinants sample clustering was gathered to define 3 groups of workers different for characteristics .

One way ANOVA with HSD Tukey adjustment was performed by SPSS package version 22 in order to compare the SI score and the sEMG data among the 3 working groups and define 3 risk profiles. Statistical significance set at $p < 0.05$.

**Figure 33** Electrodes placement protocol. An Italian worker equipped before starting the sEMG recording phase.

## 6.2 Results and discussion

***Study Population***

Forty workers were selected for the study. Each subject worked full time in the milking parlor and the mean work shift duration was 6.5 Hours (two shift per day). Mean age was 43, with average of 13 years of work experience as dairy parlor worker. Mean height was 1.71 and mean weight was 79 Kg.

Thirty eight workers were right dominant hand, while only two of them were left dominant hand. The ethnic backgrounds of the study subjects was mixed: 37% (15 subjects) were from European countries while 62.50 %(25 subjects) were not European and in particular Indian(20), Tunisian(2), Pakistani(2), and Egyptian(2).

***Demographic data and Anthropometric measurements***

Means procedures have shown that the waist high was the only anthropometric measurement different between European and not European workers and between workers aged more than 41.5(= 50" percentile). The S.I. results and the muscle activation( sEMG data) were not affected by any anthropometric measurements data

***Variables Analysis***

Multi correspondence analysis was used to verify which of the variables could be useful in order to describe our sample characteristics and assign a specific coefficient to each single risk factor.

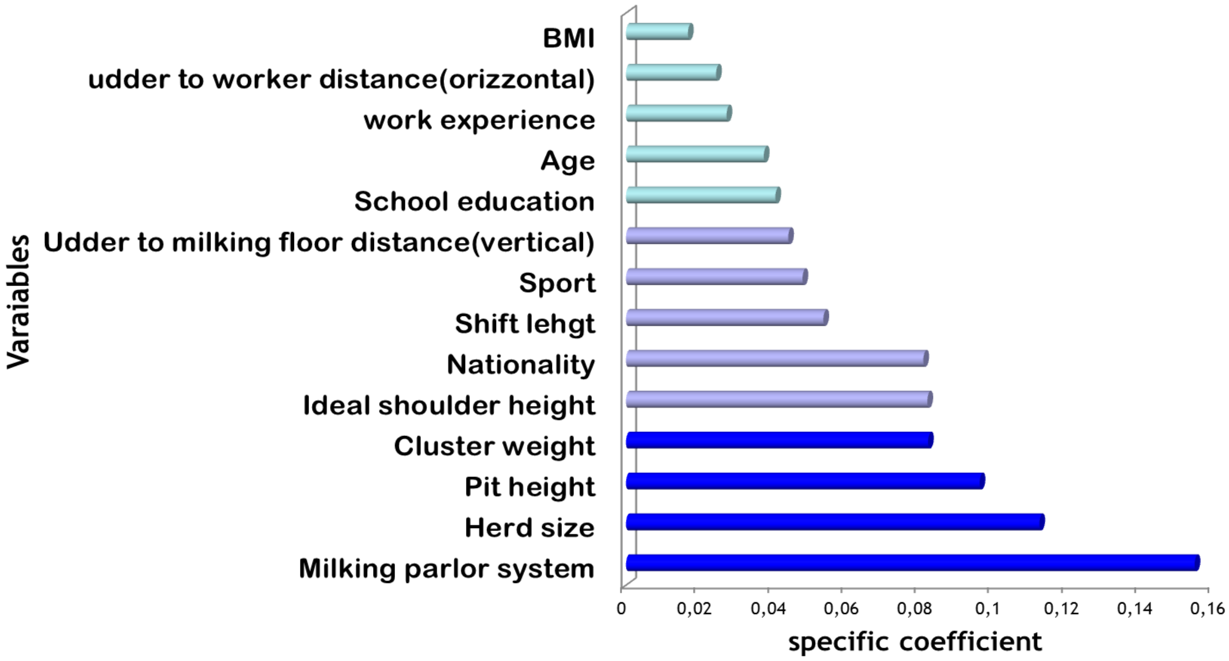



**Figure 34** Contribute of each single variable to the definition of the risk profiles

The correspondence analysis allowed the researchers to define for each variable his contribution to all the data collected (**Figure 34**). The results shown that the characteristics of the milking parlors (parlor type, pit eight, cluster weight) and organization of the work (herd size) can contribute more than other variables to the definition of our sample profile. Most of the individual demographic characteristics such as BMI, sport, age  can be considered but they seems to have a lower impact and can be considered barely important. Nationality appear to have a quite important role comparable with one of the anthropometric measurements: the ideal shoulder eight. This variable shows the difference between the ideal shoulder eight obtained by the sum of the vertical distance udder to milking floor and the pit eight (**figure 35**) and the workers' shoulder eight . Recent studies demonstrated that difference higher than 15 cm are associated with the possibility of developing MSD [126].

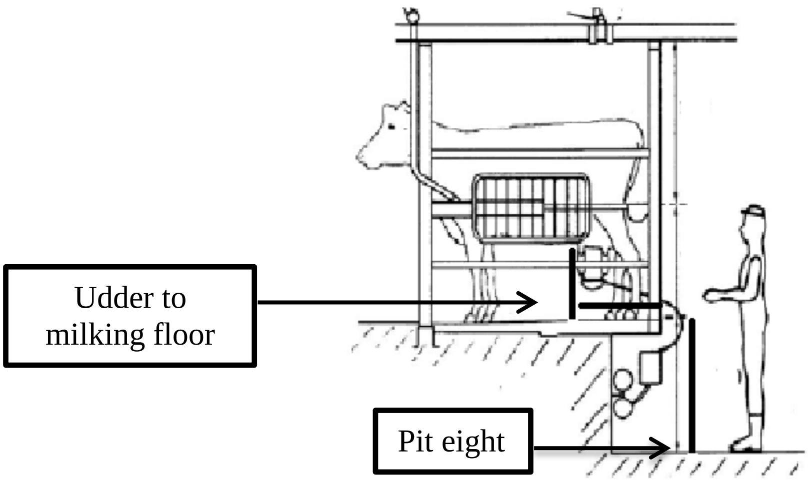



**Figure 35**Ideal shoulder eight : the sum of the pit eight and the udder to milking floor eight

Considering mainly the more predictive variables shown in figure 2 it was possible to individuate, through a sample clustering, three different groups of workers (**figure 36**). The description of the groups characteristics ($p<0.05$)  are described in **table 15**.

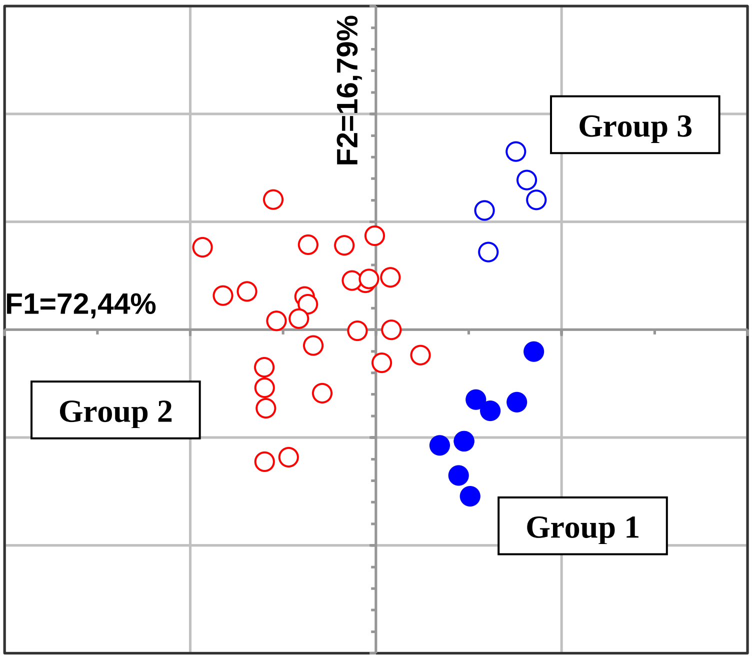



**Figure 36** Definition of different groups of workers, based on the main predictive variables

| Variables involved in MCA * | Categories | Group 1 | Group 2 | Group 3 | P Value |
|---|---|---|---|---|---|
| **Milking parlor type** | | | | | |
| | **Harringbone** | 0.00 | 84,62 | 0.00 | |
| | **Parallel** | 44.44 | 15,38 | 0.00 | p<0,0001 |
| | **Rotary** | 55.56 | 0.00 | 100.00 | |
| **Cluster weight** | | | | | |
| | **<2.4 Kg** | 55.56 | 26.92 | 100.00 | p=0,0068 |
| | **≥2.4 Kg** | 44.44 | 73.08 | 0.00 | |
| **Udder to milking floor distance** | | | | | |
| | **<53,4 cm** | 0.00 | 61.54 | 100.00 | p=0,0005 |
| | **≥53,4 cm** | 100.00 | 38.46 | 0.00 | |
| **Pit height** | | | | | |
| | **<92 cm** | 0.00 | 73.08 | 0.00 | p<0,0001 |
| | **≥92 cm** | 100.00 | 26.92 | 100.00 | |
| **Horizzontal distance(udder-edge milking floor)** | | | | | |
| | **<51 cm** | 11.11 | 69.23 | 60.00 | |
| | **≥51 cm** | 88.89 | 30.77 | 40.00 | p=0,0101 |
| **Ideal shoulder height compared with shoulder height** | | | | | |
| | **<15 cm** | 0.00 | 96.15 | 100.00 | p<0,0001 |
| | **≥15 cm** | 100.00 | 3.85 | 0.00 | |
| **Nationality** | | | | | |
| | **european** | 22.22 | 50.00 | 0.00 | |
| | **no european** | 77.78 | 50.00 | 100.00 | p=0,00599 |
| **Herd milked cows** | | | | | |
| | **<305 cows** | 0.00 | 76.92 | 0.00 | p<0,0001 |
| | **≥305 cows** | 100.00 | 23.08 | 100.00 | |
| **Working shift** | | | | | |
| | **<8 hours** | 77.78 | 88.46 | 0.00 | p=0,002 |
| | **≥8 hours** | 22.22 | 11.54 | 100.00 | |

***Multi correspondence Analysis**

**Table 15** Comparison of the 3 groups main determinants characteristics

**<u>Cluster 1(8 workers):</u>** is composed by milkers working in rotary and parallel milking parlor with pit height >92 cm, udder to milking floor >53,4 cm, and herd size > 305 cows. They are mostly not European (77%).

**Cluster 2(27 workers):** is mostly composed by workers working in Herringbone system(84%), with Cluster weight >2.4 kg(73%),pit height <92 cm,udder to milking floor <53,4 cm, , herd size < 305 cows and working shift<8 h.

**Cluster 3 (5 workers)** : is composed by milkers working in rotary parlor system, with milking cluster weight <2.4 kg, udder to milking floor distance <53,4 cm, pit eight >92 cm, milked herd size> 350 cows, the ideal shoulder eight compared with the workers shoulder eight < 15 cm, age <50 years old, not European with school education > 8 years, they play sport, and working shift> 8 hours.

***Risk profiles***

Strain Index values for each singe subtask and muscle activation data (sEMG) of the 3 groups were compared to obtain risk profiles of biomechanical overload of the wrist.

Surface EMG from the trapezius, anterior deltoid, biceps brachii, wrist flexors, and wrist extensors muscles were used to create muscle activity profiles based on normalized mean RMS, 50th percentile APDF, and %MR for the milking activities. Amplitude probability distribution function (APDF) has been used to assess the risk of developing muscular problems due to work overload. Recommendations were created for static (10th percentile), mean (50th percentile) and maximum (90th percentile) activity levels to prevent MSS and MSDs development. Static APDF activity is recommended to be below 2% MVC and never exceed 5% MVC. The recommended level for mean APDF activity should be below 10% MVC and always be below 14%. Maximum APDF activity is recommended to stay below 50% MVC and never exceed 70% MVC [136]. Strain Index values were also compared for each single subtask.

Study results shown not significant difference among the 3 groups for the average RMS muscle activity or for muscular rest percentage.

As shown in **figure 37** for the APDF 50° percentile there was significant difference between groups 2 and 3 for the wrist flexor and extensor(respectively $p=0.039$ and $p=0.038$).

Not statistically significant differences among the three groups were found for the APFD 90° and 10° Percentiles and in both cases the wrist flexor/extensor values in the 3 groups were not exceeding the recommended values. In particular, group 2 was approach the MVC recommended values of 10% MVC.

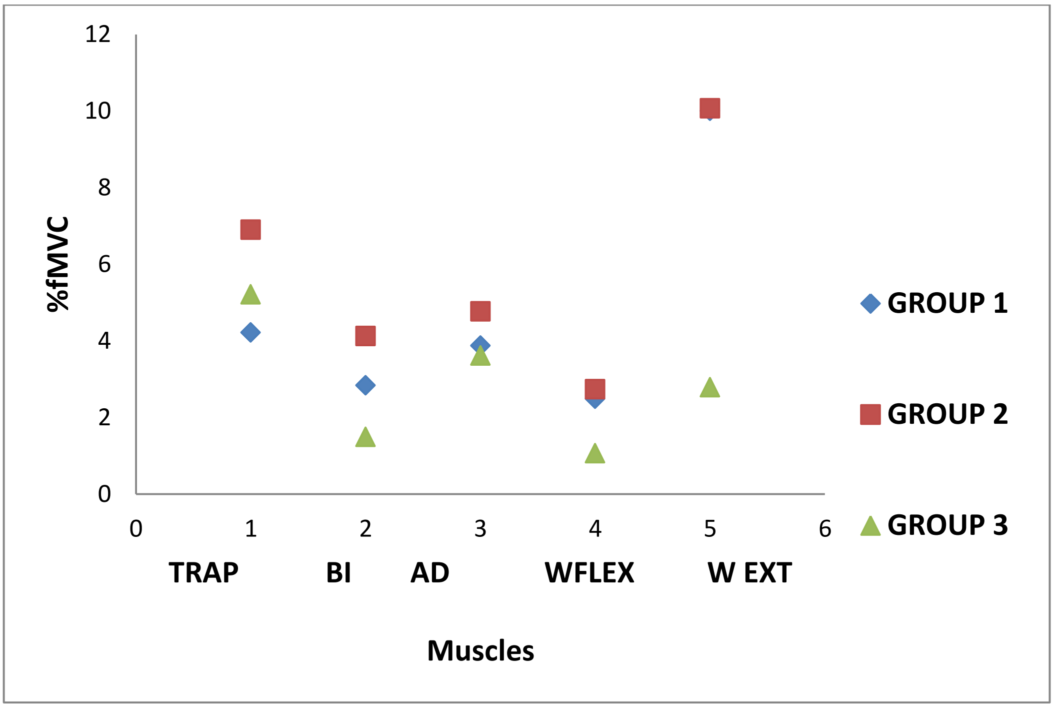



**Figure 37** Description of the three groups APDF 50 percentile

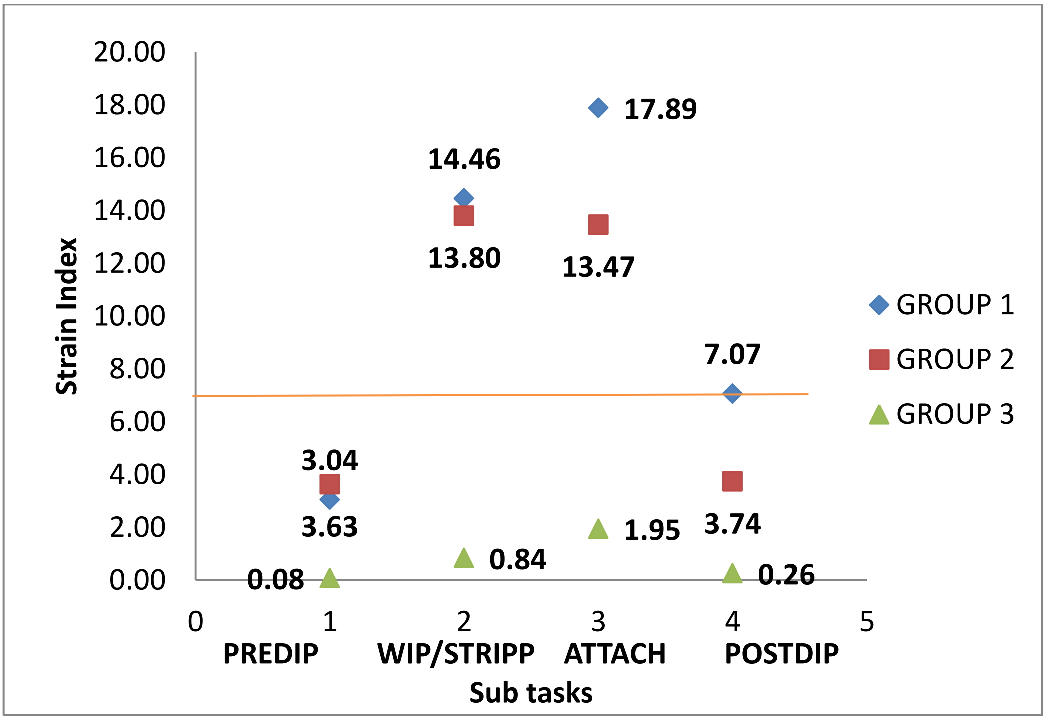



**Figure 38** Comparison of the Strain Index values for each subtask per group

For the Strain Index (**figure 38**) there were significant difference between groups 1 and 3 (p=0.040) and between groups 2 and 3 (p=0.024) for the wiping stripping phase. There were significant difference between groups 1 and 3 (p=0.040) and between groups 2 and 3(p=0.042) for the attaching phase. There were a significant difference for the post dipping phase between groups 1 and 3.

Based on the risk assessment results it was possible to define three risk profiles associated with the characteristics of the groups (**figure 39**):

*Profile 1: Medium Risk associated to the group 1*

*Profile 2: high risk associated to the group 2*

*Profile 3: Low risk associated to the group 3*

| **Characteristics** | **RISK PROFILES** | | |
|---|---|---|---|
| | **MEDIUM** | **HIGH** | **LOW** |
| | Group1 | Group 2 | Group 3 |
| Milking Parlor | Parallel/Rotary | Herringbone | Rotary |
| Cluster Weight | <2.4 kg/>2.4 kg | >2.4 kg | <2.4 kg |
| Udder to Milking floor distance | >53 cm | <53 cm | < 53 cm |
| Ideal shoulder height | < 15 cm | <15 cm | <15 cm |
| Nationality | Not European | European/not European | not European |
| Herd size | >305 cows | <305 cows | >305 cows |
| Working Shift | <8 hours | <8 hours | >8 hours |
| Pit eight | >92 cm | < 92 cm | >92 cm |
| Horizontal distance (milker -cow) | >51 cm | <51 cm | <51 cm |

**Figure 39** Risk profiles of biomechanical overload of the wrist

***Perceived exertion***

No correlation has shown up from the comparison of the perceived exertion of the worker and the observer. So there is no influence in the risk assessment of the activities in the field. In particular seems that while the observers rate is always approaching the same range for each single specific task, the worker use the whole scale to define the exertion perceived. Besides no of the occupational variables affected the workers perceived exertion.

## 6.3 Discussion

Purpose of this study was to define risk profiles of biomechanical overload of the wrist in milking parlors workers and point out, among personal and occupational variables, the ones mainly affecting the biomechanical overload of the wrist. To date a specific check list has been used to collect information about workers' personal and occupational variables and quantitative and semi-quantitative methods have been used to build risk profiles.

Our findings suggest the characteristics of the milking parlors (parlor type, pit eight, cluster weight) and organization of the work (herd size) can contribute more than other variables to the definition of the risk profiles for the wrist. These findings are in line with other field study outcomes [174] and with [126] is possible to conclude that is not sufficient to name a general risk for milkers but the individual workstation characteristics have to be considered and analyzed when assessing biomechanical risk.

Another main finding of the study was the definition of 3 exposure risk profiles: low, medium and high. Study results shown not significant difference among the 3 groups for the average RMS muscle activity or for muscular rest %. Not statistically significant differences among the three groups were found for the APFD 90° and 10° Percentiles while the APDF 50° percentile shown significant difference between groups 2(high risk) and 3(low risk) for the wrist flexor and extensor (respectively $p=0.039$ and $p=0.038$).

Recent studies affirms attaching a milking unit requires approximatively 10-15% of the Maximum volunteer contraction (MVC) [126], the present study indicated that wrist extensors mean APDF Values were close to the recommended limits for the workers included in the group 1(9,99%) and 2(10,07%), respectively medium and high risk profiles. These values are similar to those determined in a recent field study conducted in US (study 4) and some other individuated in Europe [205] by other researchers. In both studies specific milking tasks have been examined. Stal [207] indicated that extensors activity was 8.5% for the 50$^{th}$ percentile APDF. This similarity could be due to the same work activity demands conducted in small-herd dairies. Although the study results did not determine overall wrist flexors and extensors activity to be beyond the recommended levels for the 10$^{th}$, 50$^{th}$, and 90$^{th}$ APDF percentiles, wrist extensor activity was approaching the maximum threshold for the 3 groups 50th APDF percentiles. Very likely if examined in relation to each specific milking tasks, the sEMG analysis could reveal the wrist flexor and extensor muscle activity may be beyond the recommended thresholds, and that would bring about an increasing risk for developing a WRMSD such as carpal tunnel syndrome.

Besides, the main findings of the present study demonstrated the rotary milking parlors to be those in which the worker is exposed to a lower risk compared to other milking parlor types. As presumed by Duphrate et al [183] since the presence of lower movement velocities, lower repetitions and higher opportunities of for rest/recovery seems the job task rotation strategy allows milkers exposure variation.

The study indicated that pretty often the rotary milking system is common in dairy farms with more than 305 cows - that is a supposition of a quite big dairy farm in Italy - and consequently also a minimum number of two / three milkers per shift is required. Such organization would favor a better herd management and a reduction of risk in terms of biomechanical overload of the district hand - wrist. Researchers have denoted that methods performed on large-herd parlor systems may be associated of an increased risk of biomechanical overload for the milker [208,209, study 4 of the present research]. Conversely this research reveled the majority of workers operating in milking parlor with a low number of cows (<305 cows) are classified in high risk profile, as regards the muscle activation of the worker. These results are not surprising if we consider that the organization of small- milking farms requires the employee to perform the milking routines with different rhythm, often influenced by additional tasks such as: pit floor cleaning, pushing cows, antibiotics injections . These activities together with the same conformation of the milking parlor are very likely affecting more than other factors the muscles activation.

An important consideration is also worth concerning the weight of the milking unit, if greater than 2.4 kg caused increased muscle strain for the wrist of the milker, thereby confirming the statement already made by recent studies [126]. An effective prevention criteria in order to reduce the workload is achieved when light milking units (1.5 kg or less) are implemented [126]. Considering the holding side, Stal et Al [174] concluded that a support arm can reduce the load of the biceps (24%) and on flexor muscle (17%) of the forearm.

Specific characteristics of the workstation, such as the milking pit height, in the present study were not only associated with one specific risk profile . However it's interesting to underline that in the rotary milking parlors and parallel mostly associated in this study to the medium and low risk profiles the pit high is always more than 92 cm (sample median value ). However, we are cautious for such considerations as those relating to the observation of other parameters such as the nationality of the worker and the duration of the shift because they did lead to an unambiguous conclusion in terms of contribution to the identification of the risk profile.

Finally, employees working in close distance from the udder of the cow (<53 cm) would be also the same who, in parallel and rotary milking parlors, can mitigate risk and thus collocate themselves in medium and low risk profiles since the assumption that those conditions allow them to work obtain a perfect shoulder height (when the breast height pit depth minus shoulder height is <15 cm). As for the improvement of other aspects, such as productivity and efficiency, the optimization of the management of the milking activities is important to reduce the risk [210].

## 6.4 Limitations

Muscle activity measured with sEMG was collected at the beginning of each shift only, for a period of approximately one hour (1.15' h). Thus it may not well represents milking work completed throughout the entire shift. Besides variability in work rest time was noticed across the dairies because optimal work-flow pace depends from many other factors, different per dairy. The possible effects of muscle fatigue on muscle activity were not assessed in terms of physiological stress, although these could have effect %MR and APDF values. Most of the workers involved in the study are migrants from not European countries, thus it would have been interesting to assess even psychosocial factors who are responsible of musculoskeletal disorders. Further studies that consider even these risk factors may help in the definition of risk profiles.

Also animal welfare deserves attention, so a further need to address is also animal welfare issues [211]. Lastly, the small sample size limits the generalizability of findings.

## 6.5 Conclusions

Among the personal and occupational variables the present study explored the research demonstrated the characteristics of the milking parlors (parlor type, pit eight, cluster weight) and organization of the work (herd size) can contribute more than other variables to the definition of risk profiles. Three are the level of risk profiles of biomechanical overload of the wrist pointed out by our research, based on the results of Strain Index and sEMG: low, medium and high risk level. Although the sample size is not quite big, it is the first time that risk profiles have been developed for a milker population. Possible prevention criteria to reduce the risk of biomechanical overload of the wrist are:

- Good organization of the milking routine (pre-disinfection stimulation \ cleaning-attack-post disinfection). Such a measure of prevention may be difficult to apply in cases where the operator has to work alone, as in case of some workers involved in this study (herringbone and parallel milking parlors).

- Use of milking units of 2.4 kg weight or less and eventually consider the possibility to install the support arm to reduce wrist biomechanical strain of the milker.
- -Explore the possibility of installing robotic systems, if in line with production needs and the work organization.

Finally we study results shown a lower biomechanical overload of the wrist in rotary milking parlors. This system has to be considered a useful model of inspiration in the design of new facilities by the market of manufacturing companies but within corporate decisions.

# 7. Study 4: Determination of muscle activity among workers in large and small size industrialized dairy operations

## 7.1 Materials and Methods

This study has been addressed at comparing the levels of muscle activity present in two different kinds of industrial dairy operation, which is small size and large size herds. To the aim of this study, it was considered small any herd characterized by an average of 350 cows, and large any herd breeding and milking a number of cows major of 1000. Small her were selected in Italy, and large herd in USA (Colorado).

### 7.1.1 Population

**Large-herd study group**

Twenty-nine healthy parlor workers were recruited from three large-herd dairy farms in the U.S. state of Colorado. All the subjects were Latino(a) aged 18 years or older. Twenty-eight participants were male and one was female. All subjects were free from muscular pain at the time of data collection. To maintain homogeneity of the study population, all subjects were dairy workers performing the following milking tasks: pre-dipping, stripping, wiping, attaching milking clusters, and post dipping. Subjects were compensated $30 for their participation. This study was approved by the Institutional Review Board at the universities in both countries. Dairy management and all subjects provided approval and written informed consent, respectively.

**Small-herd study group**

Thirty-nine dairy workers were recruited from twenty-one small dairy farms in the Lombardy region of Italy. All the subjects were aged 18 years or older and male. Subjects were of mixed ethnic backgrounds including Italian, Romanian, Indian, Tunisian, Pakistani, and Egyptian. Workers were asked if they had any presence of musculoskeletal symptoms (MSS). All declared they were free from muscular pain at the time of data collection. To maintain homogeneity of the study population, all subjects were dairy workers performing the following milking tasks pre-dipping, stripping, wiping, attaching milking clusters, and post dipping. Dairy management and all subjects provided approval and written informed consent, respectively.

### 7.1.2 Data Collection Protocols

Anthropometric measurements and sEMG data from the anterior deltoid, upper trapezius, biceps brachii, wrist flexors, and wrist extensors were collected using a previously described collection procedure( **Appendix 2 and 3**) . Anthropometric and sEMG data were collected and processed identically in both locations to ensure consistency in the data from Italy and Colorado.

**Functional Maximum Voluntary Contraction Protocol**

Functional maximum voluntary contractions [fMVC] were collected to normalize the sEMG data in order to appropriately compare muscle groups. A 30 second baseline resting sEMG signal was collected to calculate the minimum resting activity to use in the normalization procedure. Subjects then performed three fMVC procedures (same used in study 3) to obtain functional maximum contractions for the anterior deltoid, upper trapezius, biceps brachii, wrist flexors, and wrist extensors muscles. At least three fMVC trials were administered for each subject for each muscle group. Over a three second countdown, subjects were told to ramp up to a maximum muscular effort, hold the maximum effort for four seconds, and then relax. Subjects were verbally encouraged to maintain a maximum contraction. One minute rest periods were provided between trials to minimize muscle fatigue. Upon completion of each trial, a maximum was calculated using the middle three seconds of the root mean square [RMS] processed sEMG trial data. The mean and standard deviation were determined to calculate covariance. If the covariance was above 15% for the three fMVC trials, additional trials were repeated up to a maximum of five trials.

Functional MVCs for the anterior deltoid and upper trapezius were calculated using the procedures established by Boettcher, Ginn et al. [205] . For the anterior deltoid, this was accomplished by raising the arm 120 degrees in the sagittal plane from a relaxed state. Pressure was applied proximally below the elbow to engage the anterior deltoid muscle. Subjects were instructed to maintain their arm in the elevated position. The upper trapezius fMVC was gathered using the "empty can" method Boettcher, Ginn et al. [205] . The subjects were instructed to place their arm at 90 degree flexion in the scapular plane and internally rotate the arm forcing the palm to face outward away from body centerline. Finally, subjects were instructed to simulate holding an empty soda can. Downward pressure was applied proximally below the elbow, as the subject maintained the arm in aforementioned position. Wrist flexors and wrist extensors' fMVCs were obtained simultaneously through a co-contraction with the use of a hand dynamometer (Biometrics G100, England). Subjects were instructed to form a power grip around the handle of the hand dynamometer and keep the elbow in 90 degrees of flexion. Subjects were instructed to grip with maximum effort while maintaining elbow flexion. Functional MVCs for the biceps brachialis muscle were determined using the values generated from the wrist flexor and extensors procedure.

**Milking tasks**

Subjects in large and small herd dairies had relatively similar milking routines. All of the large-herd dairy subjects completed five individual milking tasks: pre-dipping, stripping, wiping, attaching milking clusters, and post dipping. Italian subjects predominantly completed stripping, wiping, and attachment of milking clusters. Typically, pre-dipping, wiping, and post-dipping were completed with one hand while stripping and attaching required the use of both. For tasks that could be completed using either the right or left arm, subjects were instructed to use the instrumented arm. Aside from this stipulation, subjects performed the tasks per their normal routine in parallel and herringbone configured milking parlors. In rotary type parlors subjects were asked to rotate amongst the three different workstations. At the first work station, a subject completed pre-dipping and stripping directly after cows entered stalls. At the second station, the subject completed wiping and attaching. Finally, at the third station, the subject completed post dipping on cows that had been milked. By asking subjects to rotate every 20 minutes, each subject completed all the milking tasks.

To develop muscle activity profiles, it was necessary to document when the milking work was commenced. This was accomplished with the use of an event marker and a stopwatch. When the subjects began the milking shift, the event marker was triggered to mark the start within the EMG stream. A stopwatch was simultaneously started to document the total time of milking work. Data was collected for the length of time it took to completely milk a pen of cattle (225-275 cows), between 45 and 90 minutes. Once milking work was concluded the time was documented and the stopwatch turned off. The sample period was a single pen of cows rather than a fixed time frame to allow for the removal of the EMG equipment from the subjects during their short breaks in between pens when milking activity was paused.

**Muscle Activity Profiles**

Muscle activity profiles were constructed through analysis of the normalized processed sEMG data. The processed sEMG data was normalized using the fMVC data. Functional MVC data were processed with 100ms moving average [212]. The instantaneous maximum value determined from the moving average was used to normalize the processed sEMG data. Normalization was completed using an arithmetic process,

$$\%MVC = \frac{(sEMG - Rest)}{(fMax - Rest)}$$

sEMG data normalization equation

where *%MVC* was the normalized processed sEMG data, *sEMG* represents the collected data, *fMax* represents the instantaneous maximum value from fMVC trials, and *Rest* represents the minimum value from the 30 second baseline. Temporal analysis of the sEMG data was accomplished through use of the RMS processing technique [120]. A graphic user interface (GUI) program was created using MATLAB 7.10.0 (Mathworks, Natick, MA) to process the sEMG data and obtain mean RMS values. Amplitude probability distribution function (APDF) was determined for the 10$^{th}$ percentile (static), 50$^{th}$ percentile (mean), and 90$^{th}$ percentile (maximum) (Jonsson 1982) using custom software (Fethke, Anton et al. 2004) developed in LabVIEW (National Instruments, Austin, Texas). Percent muscular rest (%MR) of the sEMG was determined with a threshold of less than 0.5% MVC and gap duration of at least 0.25 seconds [213]. The same LabVIEW custom software [214] was used to determine %MR values. Muscle activity profiles were constructed for each individual muscle. This was accomplished by determining the mean RMS, ADPF, and %MR across all the subjects. The profiles provide an estimate of the overall muscle activity and recovery experienced by the dairy workers during the given time period.

### 7.1.3 Statistical Analysis

All statistical analyses were conducted using SAS 9.3 (SAS Institute Inc., Cary, NC, USA). Descriptive statistics for the subjects and muscle activity profiles were conducted. Muscle profiles were examined using a random block 2 x 86 x 5 ANOVA (Location x Subject x Muscle) with a Tukey Honest Significant Difference post hoc adjustment to determine differences in the RMS, APDF, and %MR. Statistically significant interactions between muscle and dairy location were assessed by examining the simple main effects. Anthropometric population differences were completed using Chi squared ($\chi^2$) test and by examining the likelihood ratio test statistic. Correlations between mean RMS, 50th percentile APDF, and %MR were also examined. Statistical significance was set at $p<0.05$ *a priori*.

## 7.2 Results and Discussion

**Anthropometric Analysis**

The $\chi^2$ test indicated that the two subject populations had statistically significant differences for categorical eye level height ($p=0.005$) and forward functional reach ($p<0.001$). Functional overhead reach was approaching a statistically significant difference ($p=0.06$). There were no statistically significant differences between the two subject populations for functional stature, acromial stature, weight, or BMI ($p>0.19$). These results indicate that the two study populations are relatively similar except that milkers in the small-herd dairies in Italy have longer reach than the milkers in the large-herd dairies in Colorado

**Muscle Activity Profiles**

Profiles of muscle activity were created for the muscles of interest: upper trapezius, anterior deltoid, biceps brachii, wrist flexors, and wrist extensors (**table 16**). The mean RMS ANOVA analysis detected a significant interaction (p<0.001) between the size of the dairies, and the muscles of interest when examining the fixed effects. The simple main effects of the statistically significant interaction (**table 17**) revealed significant differences for the biceps brachii (p<0.001), upper trapezius (p=0.002), and the wrist flexors (p<0.001) between the two dairy types. The anterior deltoid (p=0.43) and the wrist extensors (p=0.50) muscles were not significantly different between the locations. In each of the significant findings, the muscle activity values were determined to be higher in large-herd operations than small-herd operations. This finding was expected as large-herd dairy workers experience a higher volume of work because of larger herd size.

| ***Small Herd*** | Upper Trapezius | Anterior Deltoid | Biceps Brachii | Wrist Flexors | Wrist Exentsors |
|---|---|---|---|---|---|
| 10th Percentile | 0.66 (1.18) | 0.16 (0.88) | 0.076 (0.69) | 0.15 (1.52) | 0.23 (1.85) |
| 50th percentile | 6.28 (4.29 | 3.60 (3.99) | 4.38 (2.73) | 2.51 (2.67) | 9.23 (5.58) |
| 90th percentile | 19.50 (12.27) | 29.61 (24.31) | 19.75 (9.94) | 35.85 (48.81) | 43.43 (36.76) |
| Mean RMS | 8.46 (5.35) | 8.26 (5.23) | 6.86 (4.02) | 5.64 (4.12) | 14.60 (7.78) |
| %MR | 0.59 (1.22) | 4.98 (5.88) | 5.36 (10.10) | 4.67 (4.55) | 5.67 (3.36) |
| ***Large Herd*** | | | | | |
| 10th Percentile | 1.13 (2.07) | 0.15 (0.39) | 1.21 (2.22) | 0.54 (0.92) | 0.40 (0.59) |
| 50th percentile | 9.28 (6.61) | 3.49 (3.71) | 14.58 (11.5) | 7.41 (5.10) | 9.75 (5.70) |
| 90th percentile | 31.44 (21.04) | 43.36 (36.26) | 51.22 (38.86) | 44.11 (31.13) | 36.74 (21.40) |
| Mean RMS | 13.58 (9.19) | 9.74 (3.71) | 19.44 (13.87) | 12.73 (6.24) | 14.02 (7.73) |
| %MR | 6.64 (7.24) | 22.77 (12.75) | 9.45 (7.34) | 13.58 (8.25) | 13.16 (6.69) |

**Table 16** Muscle activity profiles per muscle

Note: Note: Mean and (SD) are shown for each muscle *n*=26 for Large herd and n=40 for Small herd. Percentiles refer to APDF analysis. Units for mean RMS and APDF are %fMVC. %MR is measured as a percentage of total working time.

| **Muscle** | **Large-herd estimate** | **Small herd estimate** | **Difference** | **Adjusted P-value** |
|---|---|---|---|---|
| Anterior Deltoid | 9.6228 | 8.2492 | 1.3736 | 0.42 |
| Upper Trapezius | 13.4744 | 8.0310 | 5.4434 | 0.002 |
| Biceps Brachii | 19.3237 | 6.8501 | 12.4736 | <0.001 |
| Wrist Flexors | 12.6175 | 5.6311 | 6.9864 | <0.001 |
| Wrist Extensors | 13.9036 | 15.0619 | -1.1583 | 0.50 |

Note: Estimates units are %fMVC.

**Table 17** Simple main effects of dairy size X muscle interaction for 50th percentile APDF

| Muscle | Large-herd estimate | Small herd estimate | Difference | Adjusted P-value |
|---|---|---|---|---|
| Anterior Deltoid | 3.4412 | 3.4806 | -0.03938 | 0.98 |
| Upper Trapezius | 9.2232 | 5.9917 | 3.2315 | 0.02 |
| Biceps Brachii | 14.5270 | 4.3477 | 10.1793 | <0.001 |
| Wrist Flexors | 7.3509 | 2.5741 | 4.7767 | 0.004 |
| Wrist Extensors | 9.6947 | 9.4415 | 0.2532 | 0.85 |

Note: Estimates units are %fMVC.

**Table 18** Simple main effects of dairy size X muscle interaction for mean RMS analysis

Amplitude probability distribution function was evaluated at the 50th, percentile. The ANOVA analysis of the 50th percentile of the APDF revealed statistically significant interactions ($p<0.001$). For the 50th percentile APDF, the simple main effects of the statistically significant interaction (**table 18**) revealed statistically significant differences for the biceps brachii ($p<0.001$), the upper trapezius ($p=0.02$), and the wrist flexors ($p=0.0004$). The anterior deltoid ($p=0.97$) and the wrist extensors ($p=0.84$) were not significantly different when comparing the two dairy types.

| Muscle | Large-herd estimate | Small herd estimate | Difference | Adjusted P-value |
|---|---|---|---|---|
| Anterior Deltoid | 22.7527 | 4.8699 | 17.8828 | <0.001 |
| Upper Trapezius | 6.6225 | 0.6185 | 6.0039 | 0.004 |
| Biceps Brachii | 9.4296 | 5.4977 | 3.9319 | 0.06 |
| Wrist Flexors | 13.5620 | 7.1109 | 6.4511 | 0.002 |
| Wrist Extensors | 13.1400 | 1.9615 | 11.1785 | <0.001 |

Note: Estimates are a percentage of total collection time

**Table 19:Simple main effects of dairy size X muscle interaction for %MR**

| ***Small Herd*** | Mean RMS | 50th Percentile APDF |
|---|---|---|
| %MR | -0.29 (<0.001) | -0.30 (<0.001) |
| 50th percentile APDF | 0.90 (<0.001) | |
| ***Large Herd*** | | |
| %MR | -0.53 (<0.001) | -0.57 (<0.001) |
| 50th percentile APDF | 0.90 (<0.001) | |

Note: Correlations were not statistically compared across herd size

**Table 20** Correlations of muscle activity profile variables

The findings from the 50$^{th}$ percentile APDF were as expected because of the higher volume of work seen in large-herd operations. Like mean RMS, the muscle activity from large-herd operations was almost double that of small-herd operations.

The %MR ANOVA analysis also indicated a significant interaction between herd size and muscles ($p<0.001$). The simple main effects of the statistically significant interaction (**table 19**) indicated that there were statistically significant differences for each of the muscles ($p<0.004$) when comparing dairy types, except the biceps brachii ($p=0.06$), which was approaching significance. The %MR values were at least twice as large for the Colorado based large-herd dairies than the Italian small-herd dairies. These results were not expected as large-herd dairies have a higher volume of milking work and a faster work pace compared to small-herd dairies, and therefore less resting time for workers.

The correlation analysis determined that overall, across all the muscles, the same statistically significant correlations were present in both Coloradan large-herd dairies and Italian small-herd dairies (**table 20**). In the small-herd dairies, mean RMS had a strong positive, statistically significant correlation with 50$^{th}$ ($R>0.89$, $p<0.001$) percentile APDF. Additionally, both mean RMS and 50$^{th}$ percentile APDF had a statistically significant negative correlation with %MR ($R<-0.29$, $p<0.001$; $R<-29$, $p<0.001$). Evaluating the individual muscles, mean RMS, and 50$^{th}$ percentile APDF had strong, statistically significant positive correlations ($R>0.75$, $p<0.001$) for each muscle at both locations. However, when examining individual muscles, %MR only had negative correlations with mean RMS and 50$^{th}$ percentile APDF for the biceps brachii ($R=-0.35$, $p=0.03$; $R=-0.42$, $p=0.01$) and the wrist flexors ($R=-0.40$, $p=0.01$; $R=-0.35$, $p=0.03$) muscles for the Italian small-herd dairies. In large-herd dairies, %MR had statistically significant negative correlations with both mean RMS ($R<-0.48$, $p<0.001$) and 50$^{th}$ percentile APDF ($R<-0.59$, $p<0.001$) for each muscle. Mean RMS and 50$^{th}$ percentile APDF should have a strong positive correlation as they are both measures of mean muscle activity. The results show that the analysis was working as intended.

Additionally, %MR should also be expected to have a negative correlation with measures of mean muscle activity. The lack of correlations for specific muscle groups in the Italian small-herd dairies was appropriate, as low %MR values were determined for the anterior deltoid, wrist extensors, and upper trapezius ( **table19**).

The primary purpose of this investigation was to determine if there were differences in muscle activity during milking work between Coloradan large-herd operations and Italian small-herd operations. This was accomplished by analyzing the mean RMS, APDF percentiles, and %MR of the upper trapezius, anterior deltoid, biceps brachii, wrist flexors, and wrist extensors associated with milking work. Additionally, the two subject populations were compared to distinguish anthropometric differences.

Surface EMG was used to quantify muscle activity to compare the effects of milking activities in large and small-herd dairies. The analysis of mean RMS, APDF percentiles, and %MR indicated that the milking activities affected the muscles of interest differently based on the herd size. The mean RMS analysis and $50^{th}$ percentile APDF revealed that in the large-herd dairies in Colorado, there was great muscle activity for the biceps brachii, upper trapezius, and the wrist flexors. Percent muscular rest further provides a clear difference between the large and small-herd dairy farms. Subjects from the large-herd farms had at least double the amount %MR compared to small-herd farms. Because the anthropometric analysis revealed only a difference in categorical forward functional reach and eye level height, but not functional working height, the differences in muscle activity cannot be attributed to the physical differences between the subject populations. Additionally, having a longer forward functional reach, as demonstrated for the Italian subjects, would allow for less shoulder flexion and in turn less anterior deltoid flexion. However, nearly identical anterior deltoid activity was indicated by both mean RMS and $50^{th}$ percentile APDF. Furthermore, %MR revealed that the Italian subjects had nearly five times less rest for the anterior deltoid muscle. This contributes to the conclusion that differences seen among the muscle activity could be due to the differences between the large-herd and small-herd dairies.

The average herd size for the Coloradan dairies was about 2200 cows and the Italian dairies averaged about 350 cows. Aside from this large difference in average herd size between the the two, milking practices differed as well. Italian dairies milked their cows only twice per day whereas in the Coloradan dairies the cows were milked three times per day. The increased herd size means more cows to milk per hour and thus a faster work pace[182]. This could explain the increased muscle activity presented at the large-herd operations. Although work pace has not been examined directly within the dairy industry, it has been examined in light assembly work, which is similar in repetitive nature and low muscular load to dairy work. Increasing work pace yielded conflicting results with regards to increased muscular load [215, 216]. suggesting that differences in work pace may not be responsible for the differences in muscle activity between large and small herd dairy workers.

Additionally, the %MR results reinforce the position that work pace is not responsible for differences in muscle activity The large-herd parlor workers had at least twice as much %MR as the small-herd parlor workers. This finding was unexpected because of the work pace and workload differences between large and small-herd operations created by the large differences in herd size. The largest differences in %MR were found in the anterior deltoid (22.8% vs 4.9%), upper trapezius (6.6% vs 0.62%), and wrist extensors (13.1% vs 2.0%) muscles, where only upper trapezius muscles displayed a statistically different level of activity between the large and small-herd operations. The low levels of %MR displayed by the Italian subjects may be a result of a high reported prevalence of musculoskeletal symptoms (MSS) among European dairy workers [159,177.178]. It was not unrealistic. for the Italian subjects to report having MSS and possibly musculoskeletal symptoms disorders (MSD). Percent muscular rest has been used to study and document the development of MSS in the upper trapezius muscles [217,218,219,220]. For repetitive work tasks with low muscular load, %MR less than 4% has been associated with an increased risk for trapezius myalgia [217]. Italian subjects had %MR less than 1% for the upper trapezius. It was therefore possible for there to be a presence of MSS in the upper trapezius muscle.

Another possible reason for the major differences in %MR is the actual milking work. Coloradan subjects performed all five the milking tasks, whereas Italian subjects focused mainly on performing only stripping, wiping, and attaching, regarding as the most strenuous of the five milking tasks tasks [160, 168, 174, 179]. Stål, Moritz et al. [160] reported that milkers thought that stripping was the most strenuous milking task followed by cluster attachment. Pinzke, Stål et al. [168] compared the muscle activity required to complete several of the milking tasks in small-herd operations and determined that attaching had a higher 50$^{th}$ percentile APDF for biceps brachii muscles(14% MVC) than stripping (5.3% MVC), and wiping (9.7% MVC).Douphrate, Gimeno et al. [179] concluded that, from worker self-reporting, that stripping and cluster attachment were the most difficult milking tasks in large-herd operations. Masci et al, [221] demonstrated with use of the Strain Index [101] that in Italian dairies, wiping, stripping, and milk cluster attachment are strenuous. In our analysis, the Italian subject population primarily completed only the most difficult of the milking tasks, while Coloradan subjects completed all of the milking tasks. The difference in milking work could explain the high difference in %MR. Percent muscular rest requires that muscle activity drop below 0.5% MVC for at least 0.25 seconds to be documented. If only the most difficult milking tasks are being completed, the total variation in muscle activity may not drop preventing %MR documentation. This was noticeable as the muscles that presented statistically higher activity, mean RMS and 50$^{th}$ percentile APDF, in the large-herd subjects also had greater variability. Therefore it was probable that the difference in %MR can be attributed to the difference in tasks performed. Additionally, it was important to note that Italian workers were required to perform parlor operation tasks in addition to the milking work. These activities included pushing cows into the parlor, cleaning the pit floor, and completing antibiotics injections. Performing these activities throughout the data collection could also attribute to the low %MR.

Dairy milking has been demonstrated to be difficult and strenuous work in both large-herd and small-herd operations [160, 168, 222,157]. There has been a high association for MSS and MSDs in dairy work in both large and small-herd operations [207, 222, 223, 157,179]. This study demonstrated that although there are clear differences between large-herd dairy farms in Colorado and small-herd dairy farms in Italy, dairy milking was difficult work regardless of location.

## 7.3 Limitations

Muscle activity measured with sEMG was collected at multiple dairies in two different countries: the U.S. and Italy. The participating dairies within each country were similarly sized, but not identical creating fluctuations in the collection time. Subjects completed the milking work for the length of time required to complete a full pen of cattle. This time lasted on average 50 minutes in Coloradan operations and roughly 70 minutes in Italian operations, which could have impacted the sEMG analysis. Additionally, data collection always commenced at the beginning of each shift in large herd operations, causing observable variability in achieving optimal work pace among different dairies. Another set of limitations arose from the completion of the milking tasks. In small-herd dairy subjects were instructed to complete the milking tasks as per normal routine. The large-herd subjects were instructed to complete the milking tasks with the instrumented arm. This created three problems. First, milking work becomes routine for many of the workers, and subjects in the large-herd dairies sometimes forgot to use the instrumented arm, negatively skewing muscle activity and %MR. A second problem arose from requiring subjects to always use the instrumented arm to complete the milking tasks, as the data collection was not an accurate portrayal of the milking work, and constant use of one arm may also inflate muscle activity and minimize %MR. The third problem developed when comparing the data as small-herd subjects performed the milking work per normal routine increasing chances that the non-instrumented arm was used to complete the milking work. If the instrumented arm was not used for this period of time, the muscle activity collected did not represent milking work positively skewing muscle activity and %MR. To overcome this problem, future research should examine milking tasks bilaterally. Finally, this investigation assumes that collecting muscle activity an hour equally represents milking work completed throughout the milking shift. Large herd operations have workers complete the milking tasks during eight to twelve hour shifts. Physiologically, we are disregarding any possible effects that muscle fatigue may have on recorded muscle activity. Future research should consider the impact that fatigue may play by examining latter portions of the shift or using full shift data.

## 7.4 Conclusions

Dairy milking in Coloradan large-herd operations demonstrated higher mean RMS, 50$^{th}$ percentile APDF, and %MR than Italian small-herd operations. The differences in mean RMS and 50$^{th}$ percentile APDF suggest that large-herd dairy workers may be more at risk to develop injuries caused through extended high average muscle activity [136]. However, %MR suggests that small-herd dairy workers are more susceptible to developing injuries caused by lack of muscular rest, such as trapezius myalgia [138]. Milking is difficult work in small and large-herd operations and both subject populations are at risk for injury.

Although this investigation presents a novel comparison between small and large-herd operations, more information is still needed to accurately compare milking between operations. Fatigue measures were not examined and their impact was not accounted for. Large herd operations run longer milking shifts than small-herd parlors, therefore examining the impact of muscular fatigue and differences between operations would be beneficial. Task based analyses should also be conducted to determine how each task compares in small and large-herd operations. Through a task based analysis, appropriate interventions could be applied more effectively. Future dairy researchers examining differences between small and large-herd operations should focus on comparing dairy operations through task-based analyses.

## 8. Conclusions

In conclusion, with this study we obtain the following results:

- The definition of 3 risk profiles of biomechanical overload of the wrist which, based on the risk levels, can be considered as low, medium and high risk. The farms involved in the present study obtained a specific risk assessment document.

  The practical application of these findings is combined in several aspect. In fact, the profiles identified can be considered by employer to conduct his own risk assessment, with a consistent reduction of the expenses, that may therefore be invested in prevention and protection of workers' health. Besides, the risk profiles and the prevention criteria identified can be the basis for the realization of on line publication of the profile, similarly to what has already been done for noise, vibrations and solar radiation, to support risk assessment according to the Italian Law 81/08. (**study 3**).
- The identification of the main risk determinants of the biomechanical overload of the wrist: the characteristics of the milking parlors (parlor type, pit eight, cluster weight) and organization of the work (herd size). These findings allow to individuate specific technical improvements that can be applied to the milking equipment and translates directly into the possibility of directing the manufacturers to produce systems that encourage the development of safe and ergonomic workstations. (E.g. milking arm weight <2.4 kg, design inspired by rotary systems). (**study 3 and 4**)

- The definition of recommendations and prevention criteria useful to reduce the overload of the wrist during the milking activities such as : a good organization of the milking routine (pre-dipping - wiping/stripping –attaching - post dipping); the use of milking units of 2.4 kg weight or less; the implementation of a support arm to reduce wrist biomechanical effort of the milker;  the installation of robotic systems, if in line with production needs and the work organization. Adopting prevention criteria is not only mandatory for the employers due to the current legislation rules in Italy, but one of the most important outcome of risk assessment that has to obtain good solutions, suitable for both  employees and employers. (**study 3**)

Apart for these general conclusions, the study pointed out :

- A specific questionnaire, symptoms based, that can be helpful as screening and monitoring tool for the health surveillance of the milkers. (**study 2**) . The novel approach proposed is able to define specific neural pattern of the subjects.  The  development of questionnaire easy to use and useful in the identification of the subject "at risk" of developing wrist MSD, may become for the physicians a proper screening and monitoring tool. The combined approach
- A simplified ultrasound protocol,  useful for the conduction of "in field" studies addressed at investigating wrist district and at identifying early changes in milking parlor workers wrists, with the use of a portable tool. In fact two putative windows considered as the most predictive for the detection of wrist disorders of milkers (extensor compartment-6 and flexor compartment-3) has been defined. The examination of the two most predictive acoustic windows and the use of a portable device may overpass the limitations related primarily to the time required to perform ultrasonography to multiple acoustic windows, but even to the difficulties in performing exams at the workers' workplace, needed in all occupational health screening. (**study 1**)

Both the above findings brought a significant improvement in the quality of health surveillance programs of agricultural workers as well as, indirectly, the safety and quality of work of the milkers.

However, we are aware that the sample size limits the generalizability of findings. Therefore new studies on a larger sample population are desirable. Moreover, since the differences revealed in the present study among milking routine as they are performed, new research should consider how each task affects the muscle fatigue in order to find even more effective prevention criteria.

Lastly, the holistic approach developed to achieve the above mentioned aims can be adopted even in different research field in order to address the issues related to the development of musculoskeletal disorders that is nowadays the principal occupational disease in the national and international scenarios.

# Appendix

UNIVERSITÀ DEGLI STUDI DI MILANO

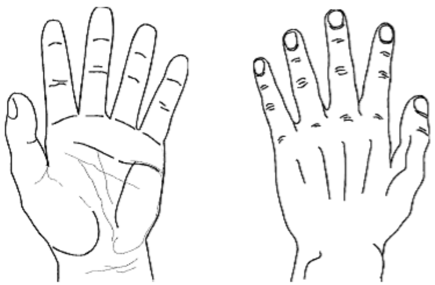
**Ph.D. in Occupational Health and Industrial Hygiene**
**at the University of Milan**
**Director: Prof. Giovanni Costa**

## 1. Symptoms Questionnaire

**LEFT HAND**

**Circle your symptoms and the severity (0-10 scale)**

| | None | | | Moderate | | | | | Severe | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **A Numbness/tingling** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **B Burn** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **C Ache** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **D Weakness** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |



**Shade-in the area of the hand where you have (had) the symptoms circled above.**

1)How long have you had these symptoms?
**2 weeks - 3 to 6 months – 6 months up to years – more than 3 years**

2)When was the last time you had these symptoms?
**In 2 weeks - 3 to 6 months ago – 6 months to 3 years ago – more than 3 years ago**

3)Do the symptoms limit your working activities? yes no

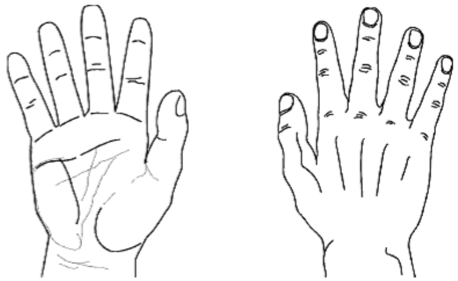
Severity of the limitations **None Moderate Severe**
0 1 2 3 4 5 6 7 8 9 10

4)Do you have any problem in opening a jar? Yes no
5)Did you try to relieve the symptoms? Yes no
6)Which is the remedy to your symptoms?______________________
7)Are you affected by cervicalgia? Yes no
8)Do you have diagnosis of cervicalgia? Yes no
9)Only if the answers to the previous questions were positive,
Have you notified any of this symptoms to a medical doctor? Yes no

**RIGHT HAND**

**Circle your symptoms and the severity (0-10 scale)**

| | None | | | Moderate | | | | | Severe | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **A Numbness/tingling** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **B Burn** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **C Ache** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **D Weakness** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |



1)How long have you had these symptoms?
**2 weeks - 3 to 6 months – 6 months up to years – more than 3 years**

2)When was the last time you had these symptoms?
**In 2 weeks - 3 to 6 months ago – 6 months to 3 years ago – more than 3 years ago**

3)Do the symptoms limit your working activities? yes no

Severity of the limitations **None Moderate Severe**
0 1 2 3 4 5 6 7 8 9 10

4)Do you have any problem in opening a jar? Yes no
5)Did you try to relieve the symptoms? Yes no
6)Which is the remedy to your symptoms?______________________
7)Are you affected by cervicalgia? Yes no
8)Do you have diagnosis of cervicalgia? Yes no
9)Only if the answers to the previous questions were positive,
Have you notified any of this symptoms to a medical doctor? Yes no

UNIVERSITÀ DEGLI STUDI DI MILANO

# Ph.D. in Occupational Health and Industrial Hygiene
# at the University of Milan
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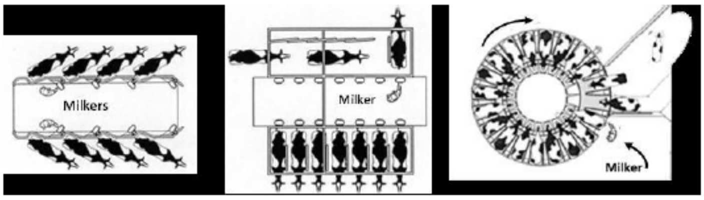
## 2. Collection data sheet

### SCHEDA RACCOLTA DATI

**Azienda** ______________________________________________ **Sede** ________________________________

**N° ID lavoratore**___ data____/____/_____ **turno** : M P S

| SALA DI MUNGITURA | |
|---|---|
| **Consistenza della Mandria** | _______ |
| **Tipologia sala** ☐ Spina di pesce ☐ Parallela ☐ Rotativa | |




| | |
|---|---|
| **Marchio** | __________ |
| **Anno di installazione** | __________ |
| **Stacco automatico** | ☐ si ☐ no |
| **Pre disinfezione** | ☐ Spray ☐ Immersione |
| **Post disinfezione** | ☐ Spray ☐ Immersione |
| **Numero vacche in mungitura** | __________ |
| **Numero delle mungiture giornaliere e relativi orari** | ☐ **mattino**______ ☐ **pomeriggio**______ ☐ **sera**_______ |
| **Numero di mungitori** | __________ |
| **Numero delle poste della sala di mungitura (es 6+6, 12+12 ecc)** | _______ |
| **Presenza di pedana sul fondo della fossa di mungitura** | ☐ si ☐ no |
| **In caso di sala a spina di pesce, angolo di inclinazione delle vacche** | ☐ **20°** ☐ **50°** ☐ **70°** |
| **Distanza mezzeria della vacca bordo fossa** | __________ |
| **Disponibilità di acqua calda per i lavaggi sia di mani sia di mammelle** | ☐ si ☐ no |

| | |
|---|---|
| **Peso gruppo mungitura** | ________ |
| **Presenza di impianto di riscaldamento funzionante** | □ si □ no |
| **Larghezza fossa di mungitura(cm)** | ________ |

| **DATI AMBIENTALI** | | |
|---|---|---|
| **Temperatura________** | **Velocità del'aria________** | **Umidità__________** |

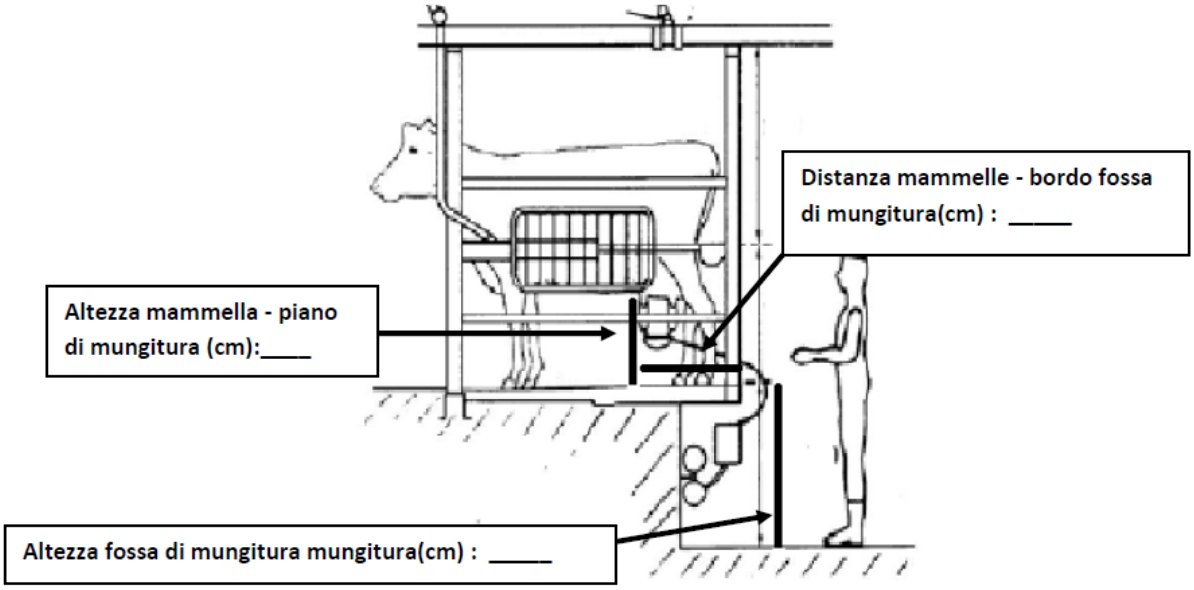



*Figura n. 1 Dimensioni della sala di mungitura*

| **DATI DEMOGRAFICI DEL MUNGITORE** | |
|---|---|
| **Età (anni)** | ________ |
| **Mano dominante** | □ DX □ SX |
| **Nazionalità** | ________ |
| **Sport** | □ si □ no |
| Se si n. di ore/settimana | ________ |
| settimane/mese | ________ |
| Mesi/anno | ________ |
| **Educazione scolastica(anni)** | ________ |

## DATI ANTROPOMETRICI DEL MUNGITORE

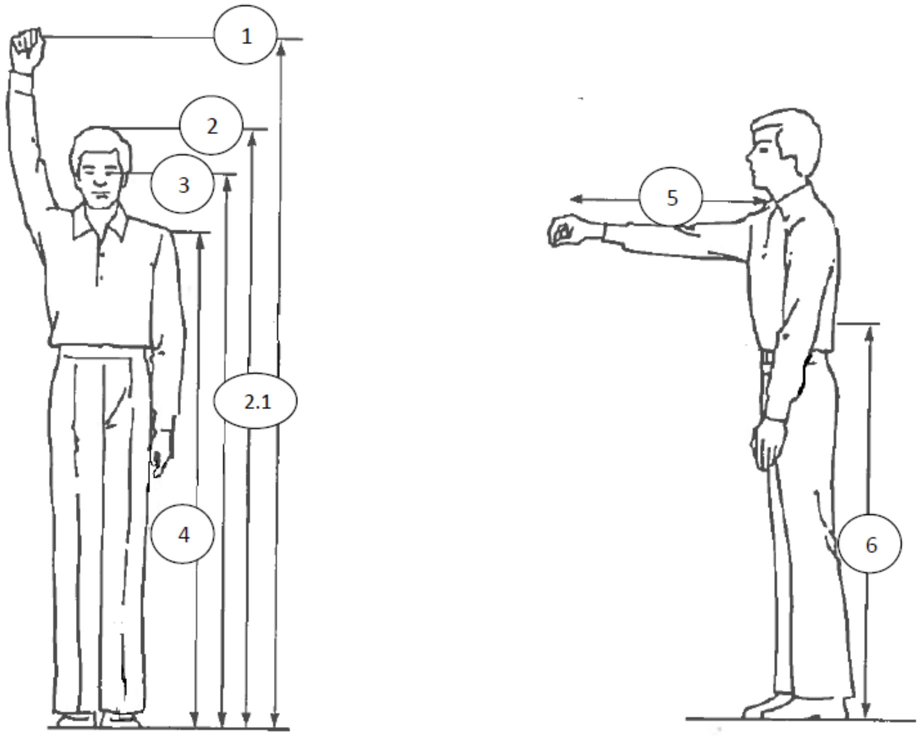



*Figura n.2. Dimensioni Antropometriche, posizione in piedi(Adattato dal libro "Design for people at work" di Suzanne H . Rodgers, Ergonomics V.1).*

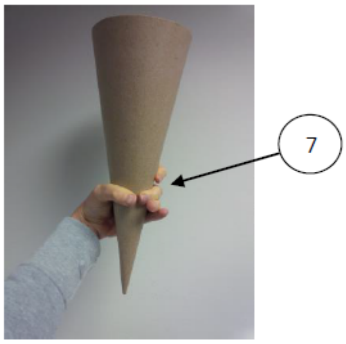



*Figura n 3. Dimensioni Antropometriche, mano.*

| | |
|---|---|
| *1.Distanza funzionale raggiungibile verticalmente con il braccio(in piedi)* | ___________ |
| *2.Statura* | ___________ |
| *2.1.Statura funzionale (con scarpe)* | ___________ |
| *3.Altezza occhi ( in piedi)* | ___________ |
| *4.(n piedi) Altezza spalle(acromio)* | ___________ |
| *5.Distanza funzionale raggiungibile orizzontalmente con il braccio( cm)* | ___________ |
| *6.Altezza "vita"(in piedi)* | ___________ |
| *7.Larghezza impugnatura, diametro interno* | ___________ |
| *8.Peso* | ___________ |
| *9. Indice di massa corporea* | ___________ |

| MILKERS TASKS | |
|---|---|
| Anzianità lavorativa nelle sale di mungitura | ________ |
| Altro lavoro attuale | ________ |
| Altro lavoro in passato | ________ |
| Tipo di turno di mungitura | □ mattino □ pomeriggio □ sera |
| Durata del turno di lavoro | ________ |
| n. infortuni(contatto fisico con animale) negli ultimi 12 mesi | ________ |

| DISPOSITIVI DI PROTEZIONE INDIVIDUALE | |
|---|---|
| Guanti | □ si □ no |

| | | |
|---|---|---|
| **Stivale antinfortunistico** | | □ si □ no |
| **Occhiali** | | □ si □ no |
| **Grembiule** | | □ si □ no |

## 3. Anthropometric data collection protocol

***Anthropometric measurements***

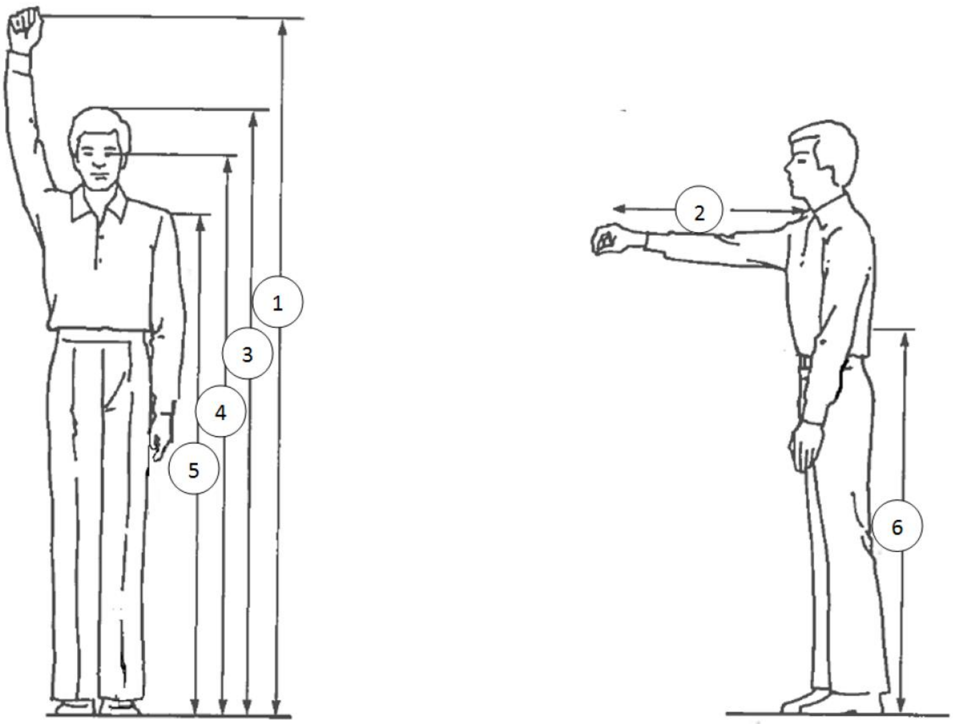



*Figure 1. Anthropometrics Dimension , Standing(Adapted from Suzanne H . Rodgers, Ergonomics Design for people at work V.1).*


*Figure n 2. Anthropometrics Dimension ,Hand. Adapted from Suzanne H . Rodgers, Ergonomics Design for people at work V.1).*

Each measure numbered in figure 1, 2 and 3 correspond to the definitions below.

| | |
|---|---|
| *1 . Functional Overhead Reach(standing)* | The subject raises the right arm as high possible as possible while keeping both feet flat on the floor. The vertical distance from the floor to the thumb knuckle is measured on the wall with a meter. |
| 2. *Forward functional reach(in cm)* | Acromial Process to Functional Pinch (standing). The subject stands erect against the wall, right arm extended forward horizontally and the tips of the thumb and index finger pressed together: shoulders remain in contact with the wall. Functional reach is measured from the shoulder, or acromial crest, to the functional grasp(knuckles fingers) with a meter. |
| 3. *Stature* | The subject stands erect, without shoes, heels together, back straight, and head in a horizontal plane defined by putting on the head of the subject a book, perpendicular to the wall. The vertical distance to the floor from the point vertex created by the wall and the set square of the book on the head of the subject is measured with a meter. The wall must not have the baseboard. |
| 3.1<br>*Functional Stature* | *(with shoes)* The subject stands erect (with shoes–<br>workstation condition), heels together, back straight, and head in a horizontal plane defined by putting on the head of the subject a book, perpendicular to the wall. The vertical distance to the floor from the point vertex created by the wall and the set square of the book on the head of the subject is measured with a meter. The wall must not have the baseboard. |
| *4. Eye height (standing)* | This height is the vertical distance from inner angle of the eye to the floor.<br>The subject stands erect (with shoes – workstation condition), heels together, back straight, and head in a horizontal plane defined by putting on the head of the subject a book, perpendicular to the wall. A set square slides perpendicular to the wall and parallel to the subject standing against the wall until reach the height of the subject's eyes. The vertical distance to the floor from the vertex created by the wall and the set square (inner angle of the eyes height) is |

| | |
|---|---|
| | measured with a meter. The wall must not have the baseboard. |
| 6. *Shoulder (Acromial)* *Height(standing)* | The subject stands erect (with shoes– workstation condition), heels together, back straight, and head in a horizontal plane defined by putting on the head of the subject a book, perpendicular to the wall. The distance from the floor to the market acromial point, the outer end of the traverse spine of the shoulder blade, on the right side is measured with a meter. |
| 6. *Waist height(standing)* | The subject stands erect (with shoes– workstation condition), heels together, back straight, and head in a horizontal plane defined by putting on the head of the subject a book, perpendicular to the wall. Waist height is measured as the vertical distance from the floor to the upper edge (iliac crest) of the right hipbone. It is measured with the same procedure used for the eye height. |
| 7. *Grip breadth, inside diameter* | The subject holds a cone at the largest circumference that can be grasped with the thumb and middle fingers just touching. The diameter of the cone corresponding to this maximum circumference is recorded. |

## 4. EMG Data collection Protocol

**Review Checklist for all Equipment**
**Electrode Placement**
1) Prepare electrodes by attaching double sided electrode tape to electrodes. This should be completed prior to subjects arriving. Prepare 10 electrodes upon arrival. Tape is used to prevent electrode movement

2) Palpate belly of muscle while having subject perform sub maximal contractions to confirm location of muscle belly (See table 1 for physical location for specific muscles). For the long head of the Biceps Brachii palpate the lateral side of the arm when arm is placed by side palms out (supine) about 3 inches below the acromion (Mattingly, 1996).

3) If any hair is present in the location intended for electrode placement, area must be shaved to remove any possible signal interference.

4) Gently scrape electrode location with sandpaper to remove any dead skin cells (Basmajian & Deluca, 1985)

5) Clean the area with an alcohol wipe.

6) Place grounding digital input on left collar bone. Make sure that ground unit makes contact with skin and is secure. If ground is not placed properly any collected data may need to removed.

7) Place electrode on skin in parallel axis to the muscle fibers to minimize any cross talk (see Table 1). This is completed one muscle at a time commencing with Trapezius. After placing electrode move to step 8.

8) Turn data logger on. Change saving location to Bluetooth. If using large data logger (M11659) press power button (left button) continue to step 9. If using small datalogger (M15153) depress joystick and skip to step 14.

9) Open Datalog program and once the Datalogger is turned on make sure that it is recognized by the computers Bluetooth connection. Under the View menu make sure that Connected Units has a check mark next to it. From here when the window pops up make sure that the unit is connected. If the unit is not seen on the window, click the scan button.

10) Connect electrode to data logger. Trapezius is input 1, Anterior Deltoid 2, Biceps 3, wrist flexors 4, and wrist extensors 5.

11) Within the Biometrics Program label each analog input with the muscle name (analog inputs from setup menu CTRL+A). Additionally, review the channel settings that the preset for the channel reads EMG. If it does not select EMG from the preset drop menu and then click preset.

12) (**Only needs to be completed once)** Change location of data storage to Bluetooth only. To review these settings scroll over to MODE using the left/right arrow. Once MODE is highlighted hold the center button and the lock button simultaneously. Then use the up/down arrows to select the mode desired: datalogger only vs Datalogger and Bluetooth vs Bluetooth only, and then press the center key.

13) Have subject perform submaximal isolated contractions. This will allow the researcher to know if the desired muscle is being collected and if the current electrode location gives a strong signal. If the signal returned is relatively weak and does not correspond accurately with flexion/extension of muscle moved electodes. If signal is deemed satisfactory repeat to step 7. After attaching all electrodes skip to step 19

14) Open Datalog program and once the Datalogger is turned on make sure that it is recognized by the computers Bluetooth connection. Under the View menu make sure that Connected Units has a check mark next to it. From here when the window pops up make sure that the unit is connected. If the unit is not seen on the window, click the scan button.

15) Connect electrode to data logger. Trapezius is input 1, Anterior Deltoid 2, Biceps 3, wrist flexors 4, and wrist extensors 5.

16) Within the Biometrics Program label each analog input with the muscle name (analog inputs from setup menu CTRL+A). Additionally, review the channel settings that the preset for the channel reads EMG. If it does not select EMG from the preset drop menu and then click preset.

17) (**Only needs to be completed once)** Change location of data storage to Bluetooth only. Depress (or Click Right)joystick. Scroll up to record. Depress (or Click Right) joystick. Scroll down to Save To. Depress (or Click Right) Joystick and scroll to Bluetooth. Depress (or Click Right) Joystick.

18) Have subject perform submaximal isolated contractions. This will allow the researcher to know if the desired muscle is being collected and if the current electrode location gives a strong signal. If the signal returned is relatively weak and does not correspond accurately with flexion/extension of muscle moved electodes. If signal is deemed satisfactory repeat to step 7. After attaching all electrodes skip to step 19

19) Place skin prep around electrode. Cover electrode with Hypafix.

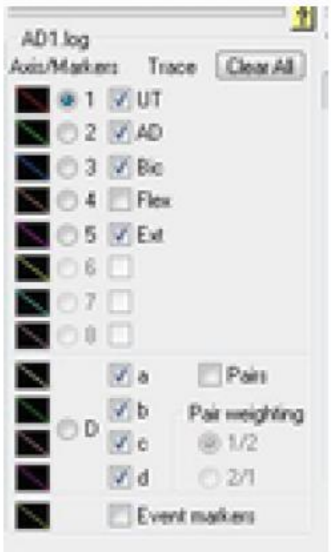
**MVC Data collection procedure (Trapezius)**

1) Have subject stand straight. Have subject place arm in a position with the shoulder abducted 90 degrees (from standing leg) and horizontally flexed 30 degress into scapular plane. Internally rotate upper arm (humerus) and extend the elbow as seen in picture at right.

2) Pressure will be placed with both arms. One arm is placed proximal to the elbow and the other distal to the elbow. Make sure not to touch any of the electrodes.

3) Explain to subject maximum effort is needed to maintain arm abducted.

4) Over a three second countdown, the subject will ramp up to maximum strength hold for 5 secs and relax.




5) Give the subject 30 secs to rest.

6) While subject is resting go to Biometrics program. Go to left most panel and make sure channel 1 is selected (See right).

7) Go to third panel (Closest to graph). Select tab 1. Select top most dropdown menu and select RMS. Click Checkbox.

8) Go to graph. Click mouse at point where muscle activity starts to rise. Hold mouse and scroll right to highlight 5 seconds of MVC activity. Release mouse. Graph should
be similar to picture below.

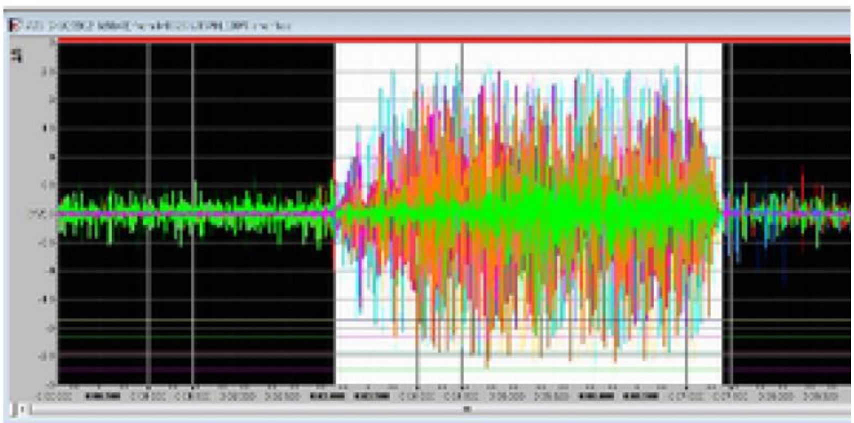


**Figure 2: RMS example**

9) Open excel sheet named Reference Cont COVAR. Go back to biometrics program. Go to bottom panel and find line highlighted in purple. Should read UT RMS. Time span should be no more than 5 seconds. Find the mean value (left most column). If mean value is not visible, right click mouse and make sure check mark is selected for mean value. Copy mean value and place into excel sheet for appropriate reference number.

| File Name | Ch | Trace Title | Filters | Units | Start Time | End Time | Time Span | Top ... | Bottom ... | Max Value | Min Value | Mean Value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AD1.log | 1 | UT | RMS | mV | 0:00.000 | 0:09.349 | 0:09.349 | | | 2.5807 | 0 | 0.4312 |
| AD1.log | 1 | UT | RMS | mV | 0:03.125 | 0:07.443 | 0:04.318 | | | 2.5807 | 0.0075 | 0.8437 |
| AD1.log | 2 | AD | RMS | mV | 0:00.000 | 0:09.349 | 0:09.349 | | | 2.3025 | 0.0007 | 0.3307 |
| AD1.log | 2 | AD | RMS | mV | 0:03.253 | 0:07.397 | 0:04.144 | | | 2.3025 | 0.0075 | 0.606 |
| AD1.log | 3 | Bic | none | mV | 0:00.000 | 0:09.349 | 0:09.349 | | | 2.3497 | -2.7525 | 0.0015 |
| AD1.log | 4 | Flex | none | mV | 0:00.000 | 0:09.349 | 0:09.349 | | | 0.435 | -0.3675 | 0 |
| AD1.log | 5 | Ext | none | mV | 0:00.000 | 0:09.349 | 0:09.349 | | | 2.0707 | -2.1473 | -0.0053 |

10) Then ask if subject is ready to proceed. If subject is read go back to step 1. Once three (3) contractions are completed proceed to step 11. If 4th contraction is finished proceed to step 12. If 5th contraction is finished proceed to step 13.

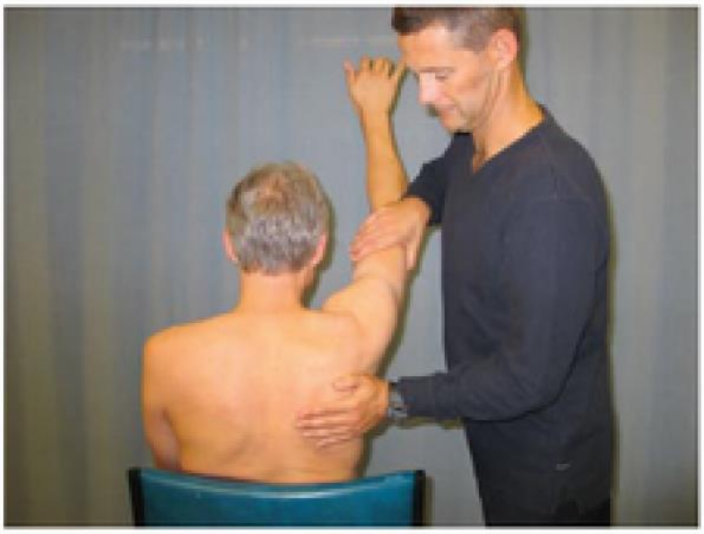
11) Go to excel sheet and examine column E **COV**. If value in cell E3 is >>>10% go back to step 1 and gather a 4th contraction. If cell E3 value is slightly greater than 10% (11-18%) go back to step 1 and gather a 4th if time permits. If cell E3 value is less than or equal to 10% continue to next muscle procedure.

12) Go to excel sheet and examine column E **COV**. Delete highest or lowest Ref value. If value in cell E3 is >>>>10% hit undo and go back to step 1 and gather a 5th contraction. If cell E3 value is slightly greater than 10% (11-18%) hit undo and go back to step 1 and gather a 5th if time permits. If cell E3 value is less than or equal to 10% continue to next muscle procedure.

13) Go to excel sheet and examine column E **COV**. Delete 2 reference values that allow cell E3 to be closest to 10%. After this is done continue to next muscle. No more than 5 contractions can be gathered.

**MVC procedure Anterior Deltoid and Biceps.**

1) Have subject stand. Have subject place arm in a position flexed roughly 125 degrees from legs as seen in picture at right.



2) To create tension, apply pressure with both arms. One arm above the elbow (proximal) and one arm below elbow (distal)

3) Explain to subject maximum effort is needed to maintain arm abducted.

4) Over a three second countdown, the subject will ramp up to maximum strength hold for 5 secs and relax.

5) Give the subject 30 secs to rest.

6) While subject is resting go to Biometrics program. Go to left most panel and make sure channel 2 is selected (See right).

7) Go to third panel (Closest to graph). Select tab 2. Select top most dropdown menu and select RMS. Click Checkbox.

8) Go to graph. Click mouse at point where muscle activity starts to rise.
Hold mouse and scroll right to highlight 5 seconds of MVC activity. Release mouse. Graph should be similar to picture below.

9) Open excel sheet named Reference Cont COVAR. Go back to biometrics program. Go to bottom panel and find line highlighted in purple. Should read AD RMS. Time span should be no more than 5 seconds. Find the mean value (left most column). If mean value is not visible, right click mouse and make sure check mark is selected for mean value. Copy mean value and place into excel sheet for appropriate reference number (ANT DELTOID).

10) Go to left most panel and make sure channel 3 is selected.

11) Go to third panel (Closest to graph). Select tab 3. Select top most dropdown menu and select RMS. Click Checkbox.

12) Go to graph. Click mouse at point where muscle activity starts to rise. Hold mouse and scroll right to highlight 5 seconds of MVC activity. Release mouse. Graph should be similar to picture below.

13) Open excel sheet named Reference Cont COVAR. Go back to biometrics program. Go to bottom panel and find line highlighted in purple. Should read Bic RMS. Time span should be no more than 5 seconds. Find the mean value (left most column). If mean value is not visible, right click mouse and make sure check mark is selected for mean value. Copy mean value and place into

excel sheet for appropriate reference number (LH Bicepts).

14) Then ask if subject is ready to proceed. If subject is read go back to step 1. Once three (3) contractions are completed proceed to step 15. If 4th contraction is finished proceed to step 16. If 5th contraction is finished proceed to step 17.

15) Go to excel sheet and examine column E **COV**. If value in cell E9 or E15 is >>>10% go back to step 1 and gather a 4th contraction. If cell E9 or E15 value is slightly greater than 10% (11-18%) go
back to step 1 and gather a 4th if time permits. If cell E9 or E15 value is less than or equal to 10% continue to next muscle procedure.

16) Go to excel sheet and examine column E **COV**. Delete highest or lowest Ref value. If value in cell E9 or E15 is >>>>10% hit undo and go back to step 1 and gather a 5th contraction. If cell E9 or E15 value is slightly greater than 10% (11-18%) hit undo and go back to step 1 and gather a 5th if time permits. If cell E9 or E15 value is less than or equal to 10% continue to next muscle procedure. DO NOT HIT UNDO

17) Go to excel sheet and examine column E **COV**. Delete 2 reference values that allow cell E9 or E15 to be closest to 10%. After this is done continue to next muscle. No more than 5 contractions can be gathered.

**MVC Procedure Wrist Flexor and Extensors**

1) Have subject stand and hold g100 or similar dynamometer.

2) Subject will squeeze dynamometer as hard as possible while keeping wrist in completely neutral position and bending elbow at 90 degrees

3) Explain to subject maximum effort is needed to maintain arm abducted.

4) Over a three second countdown, the subject will ramp up to maximum
strength hold for 5 secs and relax.

5) Give the subject 30 secs to rest.

6) While subject is resting go to Biometrics program. Go to left most panel and make sure channel 4 is selected.

7) Go to third panel (Closest to graph). Select tab 4. Select top most dropdown menu and select RMS. Click Checkbox.

8) Go to graph. Click mouse at point where muscle activity starts to rise. Hold mouse and scroll right to highlight 5 seconds of MVC activity. Release mouse.

9) Open excel sheet named Reference Cont COVAR. Go back to biometrics program. Go to bottom panel and find line highlighted in purple. Should read Flex RMS. Time span should be no more than 5 seconds. Find the mean value (left most column). If mean value is not visible, right click mouse and make sure check mark is selected for mean value. Copy mean value and place into excel sheet for appropriate reference number (Finger **Flexion** Grip).

10) While subject is resting go to Biometrics program. Go to left most panel and make sure channel 5 is selected (See right).

11) Go to third panel (Closest to graph). Select tab 5. Select top most dropdown menu and select RMS. Click Checkbox.

12) Go to graph. Click mouse at point where muscle activity starts to rise. Hold mouse and scroll right to highlight 5 seconds of MVC activity. Release mouse.

13) Open excel sheet named Reference Cont COVAR. Go back to biometrics program. Go to bottom panel and find line highlighted in purple. Should read Flex RMS. Time span should be no more than 5 seconds. Find the mean value (left most column). If mean value is not visible, right click mouse and make sure check mark is selected for mean value. Copy mean value and place into excel sheet for appropriate reference number (Finger **Extension** Grip).

14) Then ask if subject is ready to proceed. If subject is read go back to step 1. Once three (3) contractions are completed proceed to step 11. If 4th contraction is finished proceed to step 16. If 5th contraction is finished proceed to step 17.

15) Go to excel sheet and examine column K **COV**. If value in cell K3 or K9 is >>>10% go back to step 1 and gather a 4th contraction. If cell K3 or K9 value is slightly greater than 10% (11-19%) go back to step 1 and gather a 4th if time permits. If cell K3 or K9 value is less than or equal to 10% continue to next muscle procedure.

16) Go to excel sheet and examine column K **COV**. Delete highest or lowest Ref value. If value in cell K3 or K9 is >>>>10% hit undo and go back to step 1 and gather a 5th contraction. If cell K3 or K9 value is slightly greater than 10% (11-18%) hit undo and go back to step 1 and gather a 5th if time permits. If cell K3 or K9 value is less than or equal to 10% continue to next muscle procedure. DO NOT HIT UNDO

17) Go to excel sheet and examine columnK **COV**. Delete 2 reference values that allow cell K3 or K9 to be closest to 10%. After this is done continue to next muscle. No more than 5 contractions can be gathered.

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