Pipette Design and Cumulative Stress Disorders: Radical Ergonomic Improvements Needed to Prevent Injury

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Introduction

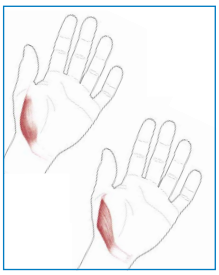
Laboratory workers who use pipettes experience a high risk of injury from work related musculoskeletal disorders (WMSD's), and the potential for long-lasting sequelae that can impair the quality of life is significant. At least three major ergonomic risk factors predispose users of these pipettes to WMSD's: awkward posture, repetition and force.

To address this issue, Federal agencies have issued guidelines and suggestions for pipetting practices to reduce the risk of injury and WMSD's. Additionally, pipette manufacturers have responded to the problem by improving the ergonomics of axial-design pipettes through the addition of buttons or plungers that require less force during aspirating, dispensing and detipping. Minor shape and grip changes have also been made in an attempt to make pipettes more comfortably fit the hand. However, both the guidelines and ergonomic changes to date still fail to overcome the fundamental problems inherent in the use of the traditional axial-design pipette: deviation of the body or extremity from an ergonomically-favorable neutral position.

Background

The pipette is one of the most essential tools in clinical and research laboratories, and is used in a variety of applications and experiments that require precise, accurate and reproducible transfer of liquids. In many settings, researchers and laboratory personnel use a pipette for several hours each day.

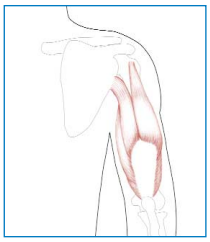
The primary hand and arm muscles that are involved during a complete pipette cycle are as follows:



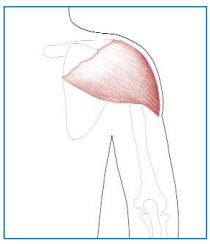
Residing at the base of the thumb, the abductor pollicus brevis muscle and the opponens pollicis muscle are used when holding a pipette, aspirating & dispensing, and for tip ejection. They allow abduction and flexion of the carpometacarpal and metacarpophalangeal joints.

The palmaris longus muscle is used during the entire pipetting cycle for wrist movement. It flexes the forearm and hand, allows side to side motions of the hand when the wrist is flexed (radial and ulnar deviation) and allows the second to fifth fingers to touch fingertips to the palm (e.g. grip a pipette).

The extensor digitorum communis and extensor digiti minimi muscles are also used during the entire pipetting cycle for wrist movement. They allow the back of the hand to bend back toward the shoulder, move the hand from side to side, and move the tips of the second to fifth fingers away from the palm.



The triceps brachii muscles, located at the back of the upper arm, are responsible for extension of the forearm and movement in elbow joint, such as when applying a tip onto a pipette.



The deltoideus muscle is used during the entire pipetting cycle for arm movement. It is primarily responsible for raising the arm to the front or to the side.

Injury Assessment and Risk Factors

The process of pipetting can be a potentially hazardous activity due to a variety of biomechanical stress factors. Lifting the upper arm in front of the body (upper arm flexion) between 45˚ and 90˚ is common throughout the pipetting task, coupled with frequent lifting of the elbow out to the side of the body (abduction of the arm). Performing tasks in a fume hood exacerbates the stresses to the shoulder and neck even further. Additionally, repetitive twisting of the forearm between the palm up and palm down positions (pronation and supination of the forearm) is also prevalent, and forearm rotation throughout the full range of motion is common at

approximately 180°. As a result of the above mentioned practices, hand and arm strength during pipetting is significantly impacted *(Figures 1 & 2),* and in this diminished capacity the user is at risk for injury.

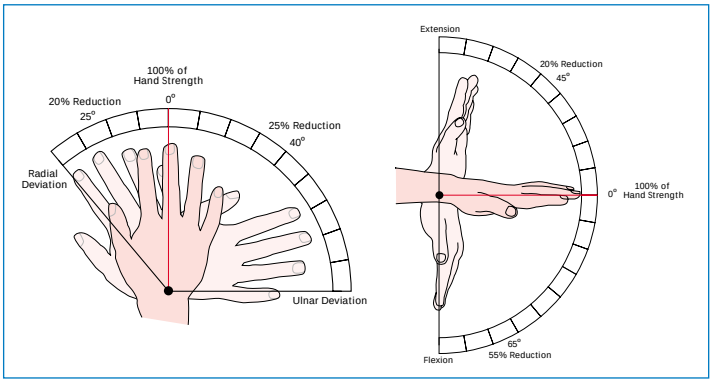


Figure 1: ***Hand strength diminishes with radial or ulnar deviation away from a neutral position***

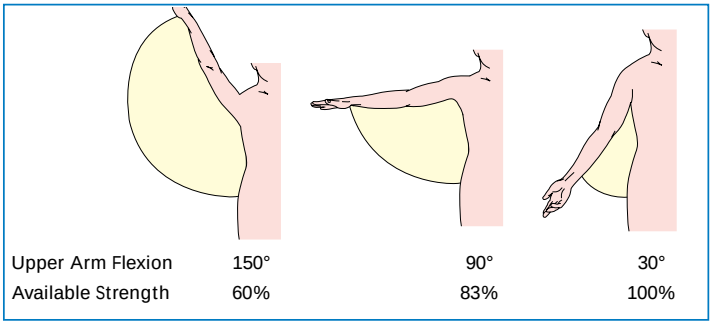


Figure 2: ***Arm strength diminishes with abduction away from a neutral position***

The use of pipettes has been linked to numerous WMSD's in laboratory workers including carpal tunnel syndrome (CTS), tendinitis, epicondylitis (tennis elbow), tenosynovitis, trigger finger, cubital tunnel syndrome, tarsal tunnel syndrome, tension neck syndrome and others. A recent study[1] of laboratory technicians found problems with hands (44%), shoulders (58%), and the neck (44%) attributable to pipetting. Another study[2] identified significant increases in hand and elbow injuries among pipetters. Other studies have also found that the amount of effort needed to move the pipette plunger during the pipetting cycle can be quite large, especially for women[3]. In general, clinical studies, case reports and biomechnical studies published to date about ergonomics and pipetting have identified awkward posture and force as important contributing factors that, when amplified with repetition, increase the risk of WMSD's. Contact stress can also be an area of concern because of the nature of manual pipetting – a firm grip on the device throughout the pipetting cycle is typically required.

Definitions

Awkward posture refers to positions of the body (e.g., limbs, joints, back) that deviate significantly from the neutral position while job tasks are performed, thereby increasing the risk of injury. The greater the deviation from neutral, the greater the risk of injury. Awkward postures increase the exertion and muscle force required to perform the task and compress soft tissues like nerves, tendons, and blood vessels.

Force refers to the physical effort needed to accomplish a motion or task. Force also refers to the degree of loading to muscles and other tissues, such as the additional physical effort that may be needed to perform tasks at increased speed or in an awkward posture. Tasks or motions that require application of higher forces place higher mechanical loads on muscles, tendons, ligaments, and joints.

Repetition is the frequency at which a motion or task is repeated with little variation in movement. The risk of WMSD's due to repetition is increased when combined with force, awkward postures, acceleration and velocity.

Contact stress results from continuous contact between a hard object and sensitive tissues. Force and repetition combine to produce mechanical friction on soft tissue and tendons that is increased when forceful exertion is used, such as the firm grip which is often needed when applying a tip onto a pipette.

1. David G., Buckle P., "A questionnaire survey of the ergonomic problems associated with pipettes and their usage with specific reference to work-related upper limb disorders", Appl Ergonomics. 1997;28(4):257-262.
2. Baker P., Cooper C., Upper limb disorder due to manual pipetting. Occup Med. 1995;48(2):133-134.
3. Fredriksson K., "Laboratory work with automatic pipettes: a study on how pipetting affects the thumb", Ergonomics. 1995;38:1067-1073.

Government and Industry Actions

Various US governmental agencies, including the National Institute for Occupational Safety and Health (NIOSH), the National Institute of Environmental Health Sciences (NIEHS) and the Office of Health and Safety System of the Centers for Disease Control and Prevention (CDC) have suggested modifying certain laboratory practices as a means for reducing exposure to the identified risk factors when pipetting. Collectively, the recommendations include:

Minimizing awkward posture by:

- Use of shorter pipettes to reduce hand elevations
- Positioning elbows as close to the body as possible, with arms and wrists extended in straight, neutral positions (handshake posture)
- Keeping work items within easy reach to limit extension of the arm or twisting of the neck and torso
- Limiting work where arms are in an elevated position
- Use of adjustable chairs or ergonomically designed stools with proper back, thigh and foot support
- Use of "low-profile" apparatus (waste receptacles, solution containers, etc.)

Minimizing force by:

- Selecting/using pipettes that require less finger or thumb movement and physical effort to aspirate or dispense fluids
- Using only the force necessary to perform a task (avoid unnecessary exertion from activities such as jamming tips)
- Retrofitting pipettes with finger trigger strips and/or foot switches
- Avoiding repeated pounding with the base of the palm (common when applying tips)

Minimizing the effects of repetition by:

- Limiting continuous pipetting to 20 minutes or less, varying activities and taking short breaks
- Sharing the workload between right and left sides of the body
- Varying tasks among pipettor types where activation motions are different
- Rotating pipetting tasks among several individuals
- Adding personnel for peak periods

Minimizing contract stress by:

- Selecting/using pipettors that best fit the hand of the person using it
- Selecting/using pipettes that use the full hand with an optional or relaxed grip span, rather than a tight grip (clenched fist)
- Avoiding sharp or hard work surfaces when resting arms or elbows; providing mats or rest pads as appropriate

Pipette manufacturers have also attempted to resolve the problem of WMSD's by adding certain ergonomically favorable features to their existing pipette designs such as plungers or buttons that require less force for aspiration and dispensing, trigger releases for aspiration, tip release buttons that reduce needed forces for tip ejection, or curved handles that fit the hand more closely and allow a more relaxed grip. Manufacturers have also been proactive in increasing the awareness of laboratory technicians about proper use of pipettes to reduce the risks of injury.

Although the various governmental agency recommendations for modifying laboratory practices and the feature changes made to traditional pipette designs have attempted to correct many of the ergonomic problems present in the task of pipetting, they have failed to recognize that the axial design itself may be the causative factor behind awkward posture in the entire upper extremity (neck, shoulder, elbow, wrist and hand).

Radical Design Necessity, Led by Required Change in Posture

We believe that a proper, more natural posture is unattainable without a complete redesign of the traditional axial design that has been prevalent in pipette manufacture for decades. The basic shape of commercially available pipettes is elongated along a single axis (typically 11¼" – 14¼" in length including tip), and requires the user to raise the hand high above the worksurface *(Figure 3)* and excessively rotate the wrist. This working posture is the primary source of the stresses to the upper extremities. The weight of the users' arm which is often held suspended (static) over the worksurface throughout pipetting tasks is also a causative factor in injuries and muscle stress. The application of exertion to grip and to manipulate an axial-designed device is an additional contributing element to injuries reported by pipette users.

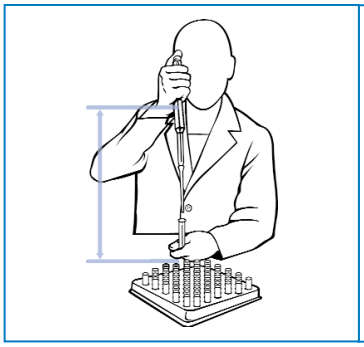


Figure 3: *Arm and hand elevation above work surface typically exceeds twelve inches*

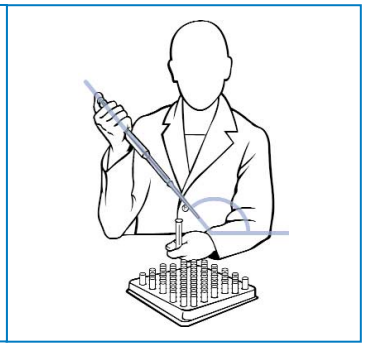


Figure 4: *Wrist rotation typically exceeds ninety degrees*

Without such a fundamental change to the overall architecture of the pipette design, the risk factors will continue to aggravate the physical stresses on the upper extremities. Further, many of the recommendations made by the various agencies are most likely in conflict with the needs of laboratory science and reasonable performance objectives, or are physically impossible to accomplish when using pipette designs currently in widespread use. Additionally, the commercial options available for replacing existing equipment with products that meet the agency recommendations are virtually non existent.

To identify ergonomic solutions that would reduce the stress and trauma caused by awkward posture, as well as the other risk factors encountered with pipetting, we have further investigated and reviewed the underlying contributing factors. Our studies revealed that key design features of pipettes that would reduce the ergonomic risk factors encountered with pipetting include:

- Replacement of the axial (elongated) design with a design that will allow the laboratory technician to work closer to the height of the bench. This design change will reduce awkward upper extremity postures and allow holding the joint of the upper arm in a neutral position.
- Adding positive tactile feedback during tip application to confirm to the laboratory worker that the tip has seated properly. This change will reduce the amount of effort (such as “pounding”) to attach the tip and therefore the effort to detip.
- Incorporation of a device or mechanism to assist in detipping.
- Provision of a grip that is appropriately contoured to the hand that would provide appropriate support during tipping and detipping.
- Provision of an adjustable grip support to minimize holding effort, yet accommodate a wide range of sizes of hands.
- Reduction of hand and finger contact pressure throughout the pipetting cycle, especially during aspirating, dispensing and detipping.

Other characteristics that could be incorporated into a new pipette design to improve usability include features to improve ease and speed of volume adjustment, legibility of the settings, soft textured grip, and placement on the bench to minimize the risk of contamination. This critical mass of ergonomic and convenience features would set a new standard for laboratory pipettes, and meet this accomplishment without compromising the needs of laboratory science and performance objectives.

Conclusions and Summary

Axially-designed pipettes are common, innocuous looking pieces of laboratory equipment that have survived decades of static design and functionality. From the enlightened perspective made possible by the field of ergonomics, it’s obvious that users of these pipettes have a high risk of developing WMSD’s because of the awkward static postures required by the traditional, axial design, the repetitive nature of pipetting, and the high forces that are often needed to operate pipettes.

Government agencies have recommended changes in work practices that primarily address reducing repetitions or reducing the potential of injury from repetition. In many cases, the needs of science or practicality within the work environment will negate these recommendations. Additionally, pipette manufacturers have focused on the problem primarily through design changes that reduce the forces needed for aspiration, dispensing, and detipping. Traditional pipettes still have elongated shapes that position not only the hand but also the entire arm, shoulder, and neck into awkward postures. In addition to adding stress to muscles and joints, awkward posture increases the required force necessary to complete pipetting tasks and further magnifies this effect through repetition. By comparison, good posture where body parts are at or near neutral alignment permits muscles and joints to operate efficiently with minimum effort levels. Instead of changing work practices, a simpler more common sense approach is to change the design of the instrument at the source of this myriad of physical problems. The need for a true ergonomic pipetting system is long overdue.

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