Occurrence of various musculoskeletal disorders in hand among smartphone addicted college going students

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Abstract:

The increasing dependence on smartphones among college-going students has revolutionized communication, education, and entertainment but has also contributed to a growing burden of musculoskeletal disorders affecting the hand and wrist. Prolonged smartphone use involves repetitive thumb movements, sustained gripping, awkward wrist postures, and continuous scrolling or texting, which increase mechanical stress on muscles, tendons, joints, and peripheral nerves. These biomechanical demands may lead to hand pain, thumb discomfort, wrist pain, reduced grip strength, muscle fatigue, De Quervain's tenosynovitis, and functional impairments that interfere with academic performance and daily activities. This review aims to summarize the current evidence on the occurrence of hand-related musculoskeletal disorders associated with smartphone addiction among college-going students and to highlight the role of physiotherapy in their prevention and management. A comprehensive literature search was conducted using PubMed, Scopus, Google Scholar, and ScienceDirect for studies published between 2016 and 2026. Epidemiological studies, systematic reviews, and clinical investigations evaluating smartphone addiction, hand and wrist disorders, and physiotherapy interventions were critically reviewed. The available evidence indicates a significant association between prolonged smartphone use and an increased prevalence of hand musculoskeletal symptoms. Greater daily screen time, higher smartphone addiction scores, poor ergonomic posture, and one-handed smartphone operation were consistently identified as important risk factors. Physiotherapy interventions, including ergonomic education, posture correction, stretching, strengthening exercises, activity modification, and patient education, have demonstrated potential in reducing symptoms, improving hand function, and preventing long-term disability. Early identification of at-risk individuals and the promotion of healthy smartphone use are essential to minimize musculoskeletal complications and improve the overall well-being of college students.

Keywords:

Smartphone addiction, Hand musculoskeletal disorders, Hand pain, Wrist pain, Thumb disorders, Grip strength, College students, Physiotherapy, Ergonomics, Upper limb disorders.

1. Introduction:

The rapid advancement of digital technology has significantly transformed modern lifestyles, making smartphones indispensable tools for communication, education, entertainment, healthcare, financial transactions, and social networking. Over the past decade, smartphone ownership has increased remarkably worldwide, with college-going students representing one of the largest and most active user groups due to their reliance on smartphones for academic and personal activities (Demirci et al., 2016). The integration of online learning platforms, virtual classrooms, digital libraries, educational applications, instant messaging services, and social media has substantially increased daily smartphone exposure among university students. While smartphones have greatly enhanced accessibility to information and improved communication efficiency, excessive and uncontrolled usage has also introduced several health concerns, including visual fatigue, sleep disturbances, psychological stress, reduced physical activity, and musculoskeletal disorders (Elhai et al., 2017). Among these health problems, musculoskeletal disorders affecting the hand and wrist have emerged as an important public health issue because smartphones require repetitive thumb movements, prolonged gripping, sustained wrist flexion, continuous scrolling, typing, gaming, and prolonged static postures, all of which impose repetitive biomechanical stress on the upper extremity (Cha & Seo, 2018). Unlike conventional computer-related musculoskeletal disorders that primarily involve keyboard and mouse use, smartphone-related disorders are characterized by repetitive thumb movements and sustained one-handed gripping patterns that place considerable stress on the muscles, tendons, ligaments, joints, and peripheral nerves of the hand (Toh et al., 2017). Continuous exposure to these repetitive mechanical loads may exceed the adaptive capacity of musculoskeletal tissues, resulting in microtrauma, inflammation, tendon irritation, muscle fatigue, reduced grip strength, impaired dexterity, and functional limitations that interfere with daily activities and academic performance (Lee et al., 2018). Recent epidemiological studies have reported an increasing prevalence of hand pain, thumb discomfort, wrist pain, De Quervain's tenosynovitis, tendon overuse injuries, and nerve compression symptoms among individuals with prolonged smartphone use (Xie et al., 2020). College-going students are particularly susceptible because smartphones are extensively used for attending online lectures, accessing educational materials, completing assignments, reading e-books, communicating with peers and faculty, participating in virtual meetings, browsing social media, streaming videos, and playing mobile games, often for several consecutive hours without adequate rest (AlAbdulwahab et al., 2017). Such prolonged exposure increases cumulative loading on the small joints and soft tissues of the hand and wrist, thereby increasing the likelihood of developing musculoskeletal symptoms. Furthermore, the growing prevalence of smartphone addiction has intensified these risks. Smartphone addiction is characterized by compulsive smartphone use, excessive screen time, inability to control usage, withdrawal symptoms when access to the device is restricted, and continued use despite awareness of adverse physical or psychological consequences (Kwon et al., 2017). Individuals with higher smartphone addiction scores generally spend longer durations using handheld devices and exhibit repetitive movement patterns that significantly increase the risk of cumulative trauma disorders affecting the upper limb (Kim et al., 2019). The human hand is an anatomically complex structure consisting of twenty-seven bones, multiple joints, intrinsic and extrinsic muscles, tendons, ligaments, synovial sheaths, and an extensive neurovascular network that together facilitate precision grip, fine motor control, and coordinated functional activities (Neupane et al., 2017). During smartphone operation, the thumb performs repetitive flexion, extension, abduction, adduction, and opposition movements while the remaining fingers continuously stabilize the device through sustained gripping. Simultaneously, the wrist is frequently maintained in flexed, extended, or deviated positions, resulting in altered biomechanics and increased compressive and tensile forces across the carpal joints and surrounding soft tissues (Gustafsson et al., 2017). Repeated performance of these movements without sufficient recovery can contribute to muscle fatigue, tendon inflammation, joint irritation, decreased grip strength, impaired hand function, and the development of chronic musculoskeletal disorders (İnal et al., 2018). Numerous observational studies have demonstrated significant associations between prolonged smartphone use and increased prevalence of upper extremity musculoskeletal symptoms, particularly involving the neck, shoulder, wrist, and hand among university students (Sharan et al., 2020). In addition to the duration of smartphone use, several ergonomic factors, including one-handed operation, poor sitting posture, awkward wrist positioning, larger screen sizes, prolonged static postures, and inadequate rest breaks, have been identified as important contributors to symptom development and progression (Berolo et al., 2016). The increasing dependence on smartphones among college-going students, coupled with prolonged daily usage and repetitive hand movements, has therefore become a major contributor to hand-related musculoskeletal disorders. Figure 1

illustrates the conceptual relationship between excessive smartphone dependency and the occurrence of musculoskeletal health concerns affecting the hand and wrist among college-going students.

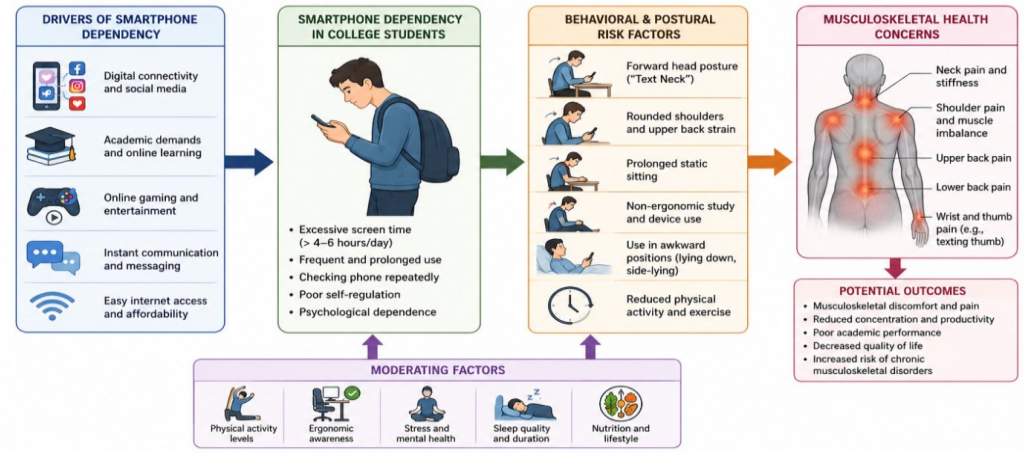

Figure. 1: Increasing smartphone dependency among college-going students and its potential association with musculoskeletal health concerns

From a physiotherapy perspective, smartphone-related hand musculoskeletal disorders represent an emerging area requiring early assessment, preventive intervention, and evidence-based rehabilitation. Physiotherapists play a crucial role in evaluating pain intensity, range of motion, muscle strength, grip and pinch strength, nerve involvement, posture, movement quality, and functional limitations using standardized clinical assessment tools (Yeun & Han, 2020). Physiotherapy management includes ergonomic education, posture correction, activity modification, stretching exercises, strengthening programs, tendon-gliding exercises, neural mobilization, manual therapy, therapeutic exercises, and patient education aimed at reducing pain, restoring function, improving muscle performance, and preventing recurrence of symptoms (Fernández-de-Las-Peñas et al., 2021). Furthermore, promoting healthy smartphone usage habits, scheduled rest breaks, regular hand exercises, and ergonomic awareness among college students may substantially reduce cumulative biomechanical stress and decrease the incidence of upper limb musculoskeletal disorders (Samaan et al., 2022). Although numerous studies have investigated smartphone addiction and upper limb pain independently, considerable variation exists regarding study design, diagnostic criteria, outcome measures, and assessment methods. Therefore, synthesizing the available evidence is essential to better understand the occurrence, underlying mechanisms, risk factors, clinical manifestations, and physiotherapy management of smartphone-induced hand musculoskeletal disorders. This review critically examines the current literature on the association between smartphone addiction and hand musculoskeletal disorders among college-going students while highlighting the important role of physiotherapy in assessment, prevention, rehabilitation, and the promotion of healthy digital device usage practices.

2. Smartphone addiction among college-going students: an emerging health concern:

Smartphone addiction has emerged as one of the most significant behavioral and public health concerns among young adults, particularly college-going students, owing to the rapid expansion of digital technology and the increasing dependence on smartphones for academic, professional, and social activities (Demirci et al., 2016). Smartphones have evolved from simple communication devices into multifunctional platforms that support online education, virtual classrooms, digital libraries, instant messaging, social networking, entertainment, healthcare applications, financial transactions, and cloud-based learning, making them indispensable in students' daily lives (Elhai et al., 2017). The widespread accessibility of high-speed internet, affordable mobile devices, and educational applications has further increased the average daily screen time among university students, many of whom spend more than six to eight hours each day interacting with smartphones for both educational and recreational purposes (Cha & Seo, 2018). While moderate smartphone use offers substantial educational and social benefits, excessive use may progress into problematic smartphone use or smartphone addiction, a

behavioral condition characterized by compulsive checking, inability to reduce usage duration, preoccupation with smartphone activities, withdrawal symptoms during periods of non-use, and continued excessive use despite experiencing negative physical, psychological, or social consequences (Kwon et al., 2017). Numerous cross-sectional studies conducted among university students have reported a high prevalence of smartphone addiction, with excessive daily usage significantly associated with poor sleep quality, reduced physical activity, anxiety, depression, impaired academic performance, and increasing musculoskeletal complaints involving the neck, shoulders, hands, and wrists (Kim et al., 2019). Among these health consequences, hand-related musculoskeletal disorders have gained increasing clinical importance because smartphone operation requires repetitive thumb movements, sustained gripping, prolonged wrist flexion, continuous scrolling, typing, gaming, and prolonged static postures that collectively generate repetitive biomechanical loading on the upper extremity (Toh et al., 2017). Continuous exposure to these repetitive movements may reduce physiological recovery time for muscles, tendons, ligaments, and peripheral nerves, leading to cumulative microtrauma, muscle fatigue, tendon irritation, reduced grip strength, and pain during functional activities (Lee et al., 2018). The intrinsic muscles of the hand, thumb flexors and extensors, forearm stabilizers, and wrist musculature remain continuously active during prolonged smartphone use, especially when devices are operated with one hand, thereby increasing muscular workload and mechanical stress (Eitivipart et al., 2018). Furthermore, smartphone addiction often encourages prolonged uninterrupted device use without adequate rest intervals, further increasing cumulative tissue loading and delaying normal musculoskeletal recovery (Xie et al., 2020). College-going students are particularly vulnerable because smartphones have become integral to their educational environment through online lectures, digital note-taking, assignment preparation, electronic textbooks, virtual discussions, research databases, and communication with faculty and peers (AlAbdulwahab et al., 2017). Outside academic settings, prolonged engagement with social media, video streaming, online shopping, mobile gaming, and entertainment applications substantially extends total daily exposure, often resulting in continuous repetitive hand movements throughout the day (Neupane et al., 2017). Several ergonomic factors further increase the likelihood of developing hand musculoskeletal disorders among smartphone users. One-handed smartphone operation requires greater thumb mobility and repetitive reaching across the touchscreen, increasing tensile loading on the abductor pollicis longus and extensor pollicis brevis tendons, structures commonly affected in De Quervain's tenosynovitis (İnal et al., 2018). Likewise, repetitive texting and gaming involve rapid flexion and extension movements of the thumb and fingers that increase muscular fatigue and tendon overuse, particularly when performed continuously without rest breaks (Sharan et al., 2020). Prolonged smartphone use below eye level also encourages sustained wrist flexion, ulnar deviation, unsupported forearm positioning, and excessive gripping force, producing abnormal compressive and tensile forces across the wrist joint and surrounding soft tissues (Berolo et al., 2016). Larger smartphone screens may require greater thumb excursion, whereas smaller screens demand repetitive precision movements, both of which contribute to cumulative biomechanical stress depending on the pattern of device use (Gustafsson et al., 2017). In addition, inadequate ergonomic awareness, poor sitting posture, prolonged static positioning, and insufficient recovery periods further increase susceptibility to hand pain, wrist discomfort, tendon irritation, reduced grip strength, and functional impairment among university students (Yeun & Han, 2020). The cumulative effects of these repetitive movements are often subtle during the early stages and may initially present as intermittent discomfort, stiffness, mild weakness, or reduced endurance before progressing to persistent pain and functional limitations if preventive measures are not implemented (Fernández-de-Las-Peñas et al., 2021). Consequently, early identification of symptoms and ergonomic risk factors is essential to prevent chronic musculoskeletal disorders. Fig. 2 illustrates the common smartphone holding postures and repetitive movement patterns that contribute to increased mechanical stress on the muscles, tendons, joints, and neural structures of the hand and wrist during prolonged smartphone use.

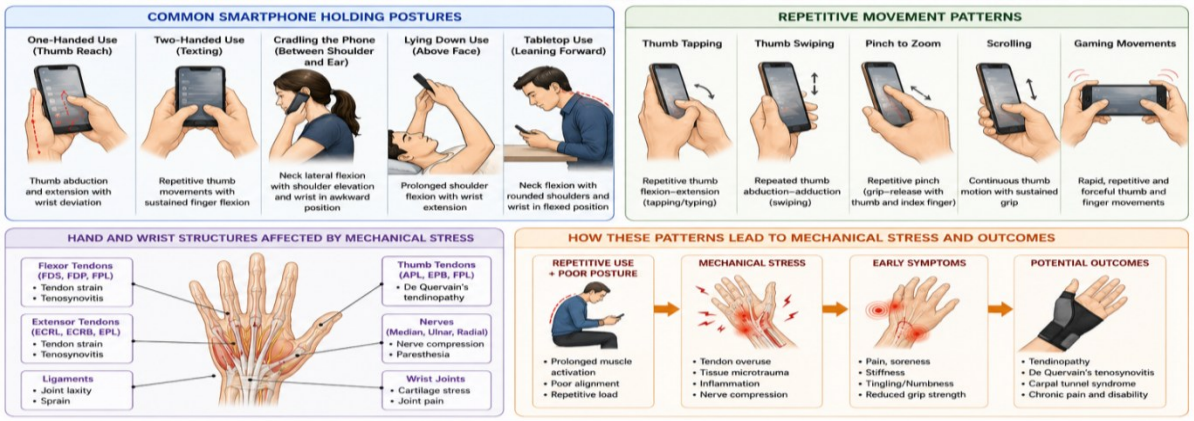

Figure. 2: Common smartphone holding postures and repetitive movement patterns contributing to mechanical stress on hand and wrist structures

The biomechanics of smartphone use demonstrate that although individual thumb and finger movements involve relatively small joint excursions, their extremely high frequency and prolonged repetition generate considerable cumulative loading on musculoskeletal tissues over time (Samaan et al., 2022). Unlike acute traumatic injuries, smartphone-related musculoskeletal disorders usually develop gradually through repetitive microtrauma and overuse, making early recognition particularly important. Symptoms such as intermittent thumb pain, wrist stiffness, reduced grip strength, muscle fatigue, decreased dexterity, tingling sensations, or diminished hand endurance should therefore be considered early warning signs requiring clinical evaluation and physiotherapy intervention (Osailan, 2021). Physiotherapists play an essential role in identifying movement dysfunctions, evaluating ergonomic risk factors, assessing muscle performance and functional limitations, and implementing evidence-based rehabilitation strategies, including ergonomic education, activity modification, stretching, strengthening, tendon-gliding exercises, posture correction, and patient education to restore optimal hand function and prevent long-term disability among college-going smartphone users.

3. Biomechanics of smartphone use and pathophysiology of hand musculoskeletal disorders:

The biomechanics of smartphone use involve a highly coordinated interaction between the thumb, fingers, wrist, forearm musculature, and peripheral neural structures, making the hand one of the most mechanically stressed regions during prolonged smartphone operation. Unlike desktop computer use, where movements are distributed between the keyboard and mouse, smartphone interaction requires repetitive small-amplitude movements performed continuously over extended periods using a single handheld device (Toh et al., 2017). Activities such as texting, scrolling, swiping, tapping, gaming, browsing, and prolonged gripping demand repetitive thumb flexion, extension, abduction, adduction, and opposition while simultaneously requiring sustained activation of the intrinsic hand muscles and wrist stabilizers (Lee et al., 2018). Although these movements appear minor individually, their extremely high repetition throughout the day produces cumulative biomechanical loading on muscles, tendons, ligaments, joints, and peripheral nerves that may eventually exceed the physiological capacity of these tissues to recover (Eitivipart et al., 2018). College-going students frequently perform these repetitive tasks for several hours daily while attending online lectures, reading digital textbooks, completing assignments, participating in social networking, or playing mobile games, thereby substantially increasing the risk of cumulative trauma disorders affecting the upper extremity (Demirci et al., 2016). The thumb serves as the primary functional digit during smartphone operation because nearly all touchscreen interactions depend upon its mobility and precision. The unique saddle-shaped carpometacarpal (CMC) joint provides remarkable freedom of movement, enabling flexion, extension, abduction, adduction, circumduction, and opposition, however, this exceptional mobility also makes the thumb particularly vulnerable to repetitive mechanical loading (Gustafsson et al., 2017). During one-handed smartphone operation, the thumb repeatedly traverses the screen while the remaining fingers maintain a sustained gripping posture, requiring continuous activation of the abductor pollicis brevis, flexor pollicis brevis, opponens pollicis, and adductor pollicis muscles to stabilize and manipulate the device (İnal et al., 2018). Continuous activation of these muscles without sufficient recovery may result in muscular fatigue, reduced endurance, altered motor control, and decreased functional performance, particularly among heavy smartphone users (Kim et al., 2019). Furthermore, repetitive thumb excursions increase friction

within the tendon sheaths surrounding the abductor pollicis longus and extensor pollicis brevis tendons located in the first dorsal compartment of the wrist, predisposing these structures to overuse injuries and inflammatory changes (Neupane et al., 2017). Excessive tendon loading may produce localized pain, tenderness, swelling, reduced thumb mobility, diminished grip strength, and difficulty performing routine functional tasks, symptoms commonly associated with De Quervain's tenosynovitis, one of the most frequently reported tendon disorders related to repetitive smartphone use (Xie et al., 2020). The term "smartphone thumb" or "texting thumb," although not recognized as a formal medical diagnosis, is widely used to describe this spectrum of overuse-related symptoms involving thumb pain, stiffness, weakness, fatigue, and impaired dexterity following prolonged smartphone use (Sharan et al., 2020). In addition to thumb-related disorders, wrist biomechanics are substantially influenced by smartphone usage patterns. Most individuals hold smartphones with the wrist maintained in slight flexion, extension, or ulnar deviation while the forearm remains unsupported for prolonged periods, resulting in altered joint alignment and abnormal distribution of mechanical forces across the wrist complex (Berolo et al., 2016). Sustained wrist flexion increases loading on the flexor tendons, elevates pressure within the carpal tunnel, alters tendon excursion, and increases fatigue of the forearm stabilizing muscles responsible for maintaining wrist posture (Yeun & Han, 2020). Similarly, prolonged ulnar deviation changes the line of pull of several forearm muscles and increases compressive forces across the radiocarpal joint, reducing movement efficiency and increasing the likelihood of cumulative tissue irritation (Fernández-de-Las-Peñas et al., 2021). Static muscular loading also plays a critical role in the pathophysiology of smartphone-related musculoskeletal disorders. Although smartphone movements involve relatively low external loads, continuous isometric contraction of the intrinsic hand muscles, extrinsic finger flexors, wrist extensors, and forearm stabilizers is necessary to support and stabilize the device during prolonged use (Samaan et al., 2022). Sustained low-level muscle activation decreases local blood flow, impairs oxygen delivery, promotes the accumulation of metabolic by-products, and accelerates muscular fatigue, thereby contributing to discomfort, reduced endurance, and diminished functional performance (Cha & Seo, 2018). According to the principles of repetitive strain injury (RSI), repeated mechanical loading without adequate tissue recovery gradually exceeds the adaptive capacity of muscles, tendons, ligaments, and neural structures, resulting in microtrauma, inflammatory responses, collagen disruption, and progressive functional impairment (Elhai et al., 2017). Repetitive thumb movements combined with sustained gripping and prolonged smartphone exposure therefore create ideal conditions for the development of overuse injuries involving the hand and wrist. Neural structures may also be adversely affected by prolonged smartphone use. The median nerve, which traverses the carpal tunnel to supply motor and sensory innervation to the thumb, index finger, middle finger, and part of the ring finger, is particularly susceptible to increased pressure associated with sustained wrist flexion and repetitive hand activity (Osailan, 2021). Although smartphone use alone is not considered a direct cause of carpal tunnel syndrome, prolonged wrist positioning, repetitive finger movements, and continuous gripping may increase median nerve irritation in susceptible individuals, leading to symptoms such as tingling, numbness, burning pain, reduced grip strength, diminished pinch strength, and impaired manual dexterity (AlAbdulwahab et al., 2017). These symptoms may become more pronounced following prolonged smartphone use or repetitive texting sessions and may interfere with both academic and functional activities if left untreated. The cumulative biomechanical effects of repetitive thumb movements, tendon overloading, sustained muscle contraction, altered wrist mechanics, and neural compression illustrate the multifactorial nature of smartphone-induced hand musculoskeletal disorders. Figure 3 presents the principal anatomical structures commonly affected by excessive smartphone use, including the thumb tendons, wrist joint complex, intrinsic hand muscles, flexor tendons, and median nerve pathway, highlighting the biomechanical basis for pain, weakness, reduced grip strength, and functional impairment observed among college-going students.

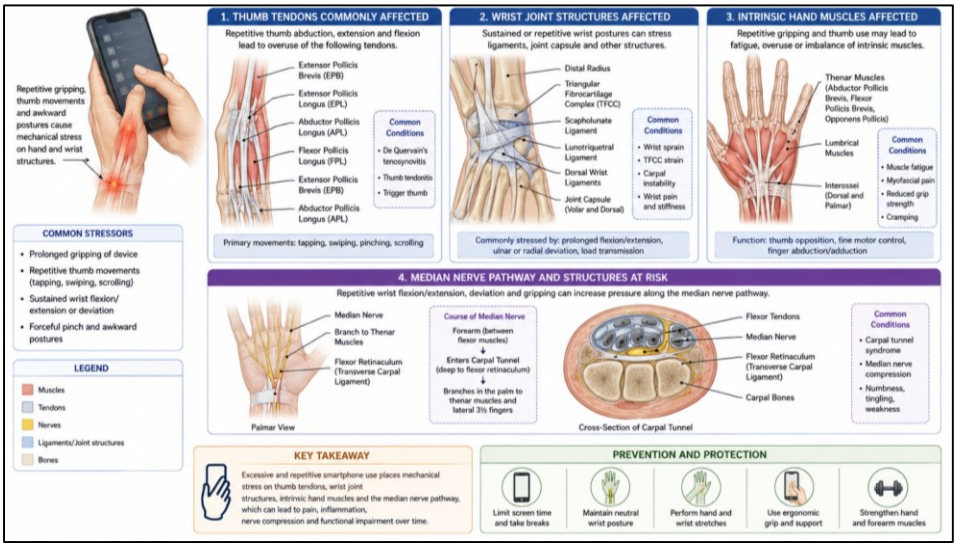

Figure. 3: Anatomical structures of the hand and wrist commonly affected by excessive smartphone use, including thumb tendons, wrist joint structures, intrinsic hand muscles, and median nerve pathway

From a physiotherapy perspective, understanding these biomechanical mechanisms is fundamental for designing effective prevention and rehabilitation strategies. Early ergonomic assessment, correction of faulty smartphone handling techniques, scheduled rest breaks, stretching of the thumb and wrist musculature, tendon-gliding exercises, strengthening of intrinsic hand muscles, neural mobilization, posture correction, and patient education can effectively reduce cumulative mechanical stress, improve hand function, and minimize the long-term risk of smartphone-related musculoskeletal disorders among college-going students.

4. Various musculoskeletal disorders of the hand associated with smartphone addiction:

Excessive smartphone use has emerged as a major contributor to upper-limb musculoskeletal disorders among college-going students, with the hand and wrist being the most frequently affected anatomical regions because of their continuous involvement during smartphone operation (Demirci et al., 2016). The increasing dependence on smartphones for academic learning, online communication, social networking, gaming, and entertainment has substantially increased the duration of repetitive hand activities performed each day, thereby exposing musculoskeletal tissues to cumulative biomechanical stress (Elhai et al., 2017). Numerous epidemiological studies have demonstrated that prolonged smartphone use is associated with a higher prevalence of hand pain, thumb discomfort, wrist pain, muscle fatigue, reduced grip strength, tendon overuse injuries, and functional limitations among university students (Cha & Seo, 2018). The severity of these symptoms varies according to several factors, including daily smartphone usage duration, frequency of repetitive thumb movements, device size, one-handed operation, ergonomic posture, physical activity level, muscular endurance, and individual anatomical variations (Toh et al., 2017). Among all smartphone-related disorders, thumb pain commonly referred to as smartphone thumb syndrome or texting thumb is one of the earliest and most frequently reported complaints (Lee et al., 2018). During smartphone interaction, the thumb performs repetitive flexion, extension, abduction, adduction, and opposition while simultaneously stabilizing and manipulating the device, resulting in repetitive loading of the thumb muscles and tendons (Eitivipart et al., 2018). This repetitive movement pattern may be repeated thousands of times daily, gradually exceeding tissue tolerance and leading to muscle fatigue, tendon irritation, pain during thumb movement, reduced mobility, stiffness, diminished grip performance, and difficulty performing functional activities requiring precision grip (Kim et al., 2019). Unlike routine manual activities that involve alternating movement patterns, smartphone interaction repeatedly recruits the same muscle groups with minimal recovery time, increasing the risk of cumulative overuse injuries (Neupane et al., 2017). One of the most clinically significant tendon disorders associated with repetitive smartphone use is De Quervain's tenosynovitis, an overuse condition involving inflammation and thickening of the tendon sheath surrounding the abductor pollicis longus (APL) and extensor pollicis brevis (EPB) tendons within the first dorsal compartment of the wrist (İnal et al., 2018). Repetitive thumb abduction combined with wrist deviation during prolonged texting, scrolling, gaming, and one-handed smartphone operation increases friction within these

tendons, resulting in radial-sided wrist pain, tenderness over the radial styloid, pain during thumb movement, reduced grip strength, and difficulty lifting or grasping objects (Xie et al., 2020). Physiotherapy plays an essential role in managing De Quervain's tenosynovitis through activity modification, ergonomic correction, thumb and wrist splinting, stretching exercises, progressive strengthening, manual therapy, tendon-gliding exercises, and patient education to reduce mechanical stress and restore functional mobility (Sharan et al., 2020).

Table. 1: Common Hand and Wrist Musculoskeletal Disorders Associated with Excessive Smartphone Use

Musculoskeletal Disorder	**Affected Structure**	**Common Symptoms**	**Possible Smartphone-Related Mechanism**
Smartphone thumb syndrome	Thumb muscles and tendons	Thumb pain, stiffness, fatigue	Repetitive thumb movement during texting and scrolling
De Quervain's tenosynovitis	APL and EPB tendons	Radial wrist pain, gripping difficulty	Excessive thumb abduction and wrist deviation
Wrist tendinopathy	Wrist flexor/extensor tendons	Wrist pain and reduced movement	Sustained wrist posture and repetitive activity
Carpal tunnel symptoms	Median nerve	Tingling, numbness, weakness	Prolonged wrist flexion and increased carpal tunnel pressure
Muscle fatigue	Intrinsic hand and forearm muscles	Reduced endurance and discomfort	Continuous static gripping and prolonged smartphone holding

Table. 1 summarizes the principal hand and wrist musculoskeletal disorders associated with excessive smartphone use, highlighting the affected anatomical structures, characteristic clinical manifestations, and the repetitive biomechanical mechanisms responsible for their development. Wrist pain represents another highly prevalent complaint among smartphone users because the wrist functions as the principal stabilizing link between the forearm and hand during device manipulation (Berolo et al., 2016). Prolonged smartphone use frequently requires sustained wrist flexion, extension, radial deviation, or ulnar deviation depending on the user's posture and grip technique, thereby increasing compressive and tensile forces across the wrist joint and surrounding tendons (Gustafsson et al., 2017). Continuous activation of the wrist flexor and extensor muscles during scrolling, typing, gaming, and prolonged device holding may produce cumulative tendon loading, muscle fatigue, localized inflammation, reduced wrist mobility, pain during gripping, and decreased tolerance for prolonged manual activities (Yeun & Han, 2020). Physiotherapy assessment of smartphone-related wrist disorders should include evaluation of joint range of motion, muscle strength, grip and pinch strength, tendon loading response, pain provocation tests, posture analysis, and functional limitations to guide individualized rehabilitation programs (Fernández-de-Las-Peñas et al., 2021). In addition to tendon disorders, prolonged smartphone use may contribute to median nerve-related symptoms resembling those observed in carpal tunnel syndrome (CTS), particularly among individuals who maintain prolonged wrist flexion while gripping the device (Samaan et al., 2022). The carpal tunnel is a narrow fibro-osseous canal containing the median nerve and flexor tendons, and sustained wrist flexion may reduce tunnel dimensions while increasing pressure on the median nerve (Osailan, 2021). Consequently, smartphone users may experience tingling, numbness, burning sensations, reduced grip endurance, hand weakness, impaired fine motor control, and sensory disturbances involving the thumb, index finger, middle finger, and radial half of the ring finger (AlAbdulwahab et al., 2017). Although smartphone use alone is not considered an independent cause of CTS, repetitive hand activity and prolonged static wrist positioning may aggravate pre-existing nerve compression or increase susceptibility among predisposed individuals (Aalberg et al., 2023). Physiotherapy management includes neural mobilization exercises, wrist posture correction, ergonomic education, flexibility training, strengthening of wrist stabilizers, tendon-gliding exercises, and activity modification to reduce median nerve irritation and improve hand function (Woo et al., 2021). Another condition receiving increasing attention is trigger finger (stenosing tenosynovitis),

which is characterized by painful catching, clicking, or locking of one or more fingers during movement due to impaired gliding of the flexor tendons beneath the annular pulley system (Yoon et al., 2020). Although traditionally associated with occupational repetitive activities, continuous smartphone tapping, repetitive typing, gaming, and touchscreen interaction may contribute to repetitive tendon friction and inflammation in susceptible individuals (Li et al., 2022). Clinical manifestations include finger stiffness, pain during finger flexion or extension, clicking sensations, reduced manual dexterity, and difficulty performing gripping activities. While direct evidence linking smartphone use to trigger finger remains limited, excessive repetitive digital movements are increasingly recognized as potential contributing factors (Park et al., 2021). Finally, excessive smartphone use may adversely influence grip strength, an important indicator of overall hand function and occupational performance (Kwon et al., 2017). Maintaining a smartphone requires prolonged isometric contraction of the finger flexors, thumb muscles, intrinsic hand muscles, and forearm stabilizers, resulting in muscle fatigue, reduced endurance, and diminished force-generating capacity following prolonged device use (Sohn et al., 2019). Several studies involving university students have reported significant associations between higher smartphone addiction scores and decreased grip strength, reduced pinch strength, impaired manual dexterity, and lower hand functional performance (Rahman et al., 2024). Reduced grip strength may negatively affect handwriting, carrying objects, opening containers, sports participation, laboratory work, clinical procedures, and numerous academic activities requiring fine motor control. Physiotherapists commonly assess grip strength using a calibrated hand dynamometer, allowing objective evaluation of functional impairment and monitoring of rehabilitation outcomes. Evidence-based rehabilitation programs focusing on progressive resistance exercises, endurance training, intrinsic hand muscle strengthening, tendon-gliding exercises, ergonomic correction, postural education, and structured activity modification have demonstrated considerable potential in improving hand strength, restoring function, reducing pain, and preventing long-term disability associated with excessive smartphone use among college-going students.

5. Prevalence and associated risk factors among college-going students:

College-going students represent one of the populations most vulnerable to smartphone-related hand musculoskeletal disorders because smartphones have become indispensable tools for academic learning, communication, research, entertainment, and social interaction, resulting in prolonged daily exposure to repetitive upper-limb activities (Demirci et al., 2016). The rapid expansion of online education, virtual classrooms, electronic learning resources, social networking platforms, mobile gaming, and digital communication has substantially increased smartphone dependency among university students worldwide, leading to growing concerns regarding the development of musculoskeletal disorders affecting the hand and wrist (Elhai et al., 2017). Recent epidemiological studies have consistently demonstrated a high prevalence of smartphone-associated musculoskeletal symptoms among college students, although reported prevalence rates vary considerably because of differences in study design, sample characteristics, diagnostic criteria, assessment instruments, cultural practices, and definitions of excessive smartphone use (Cha & Seo, 2018). The most frequently reported symptoms include thumb pain, wrist discomfort, hand fatigue, finger stiffness, reduced grip strength, forearm discomfort, muscle weakness, tingling sensations, and reduced manual dexterity, all of which may interfere with academic performance, occupational tasks, and activities of daily living (Toh et al., 2017). Several studies have suggested that symptom severity is influenced not only by the total duration of smartphone use but also by the pattern of use, with continuous smartphone interaction without adequate rest intervals producing greater cumulative tissue loading than intermittent usage (Lee et al., 2018). The repetitive biomechanical demands imposed on the thumb, fingers, wrist, and forearm during prolonged smartphone use may gradually exceed tissue adaptation, resulting in cumulative microtrauma, muscle fatigue, tendon irritation, reduced endurance, and functional impairment (Eitivipart et al., 2018). Among the numerous behavioral risk factors identified, daily smartphone usage duration remains one of the strongest predictors of hand musculoskeletal disorders (Kim et al., 2019). University students who use smartphones for more than four to six hours per day consistently report significantly higher frequencies of thumb pain, wrist discomfort, reduced grip strength, tendon-related symptoms, and muscle fatigue compared with those who limit their daily screen time (Neupane et al., 2017). Extended smartphone exposure increases cumulative mechanical loading through repetitive thumb movements, prolonged gripping, continuous static muscle activation, sustained wrist flexion, repetitive scrolling, and inadequate tissue recovery, thereby increasing susceptibility to overuse injuries (İnal et al., 2018). Another important determinant is the severity of smartphone addiction, which influences both the

frequency and duration of device interaction (Xie et al., 2020). Individuals with higher smartphone addiction scores typically demonstrate compulsive checking behavior, prolonged screen exposure, reduced rest intervals, increased nighttime smartphone use, and greater dependence on digital communication, all of which contribute to repetitive mechanical loading of the upper extremity (Sharan et al., 2020). Standardized assessment instruments such as the Smartphone Addiction Scale (SAS) and the Smartphone Addiction Scale–Short Version (SAS-SV) are widely used to quantify problematic smartphone use and have demonstrated significant associations with musculoskeletal complaints among university populations (Kwon et al., 2017). Hand dominance also influences the distribution of biomechanical loading during smartphone operation because most individuals predominantly use their dominant hand for gripping, typing, and touchscreen navigation (Berolo et al., 2016). Continuous loading of the same thumb, wrist, and forearm structures may increase localized fatigue, tendon stress, and muscle overuse compared with alternating hand use. Furthermore, one-handed smartphone operation requires greater thumb excursion across the touchscreen and increased activation of the thumb musculature to reach distant screen areas, thereby increasing tensile stress on the thumb tendons and surrounding soft tissues (Gustafsson et al., 2017). Larger smartphone screens may further increase thumb stretching and repetitive movement amplitude, particularly among users with smaller hand dimensions, thereby increasing mechanical demand on the carpometacarpal joint and first dorsal compartment tendons (Yeun & Han, 2020). Several investigations have also explored gender differences in smartphone-related musculoskeletal disorders, with many studies reporting a higher prevalence of symptoms among female students (Fernández-de-Las-Peñas et al., 2021). These differences may be explained by anatomical variations such as smaller hand size, lower muscle strength, increased thumb excursion during one-handed smartphone use, hormonal influences on connective tissue, and differences in smartphone usage behavior or symptom reporting (Samaan et al., 2022). Although the exact mechanisms remain under investigation, gender-related anatomical and behavioral characteristics appear to influence susceptibility to repetitive strain injuries associated with prolonged smartphone use. Another major contributor is poor ergonomic practice, which significantly increases biomechanical stress on the hand and wrist during smartphone interaction (Osailan, 2021). Common ergonomic errors include prolonged unsupported smartphone holding, excessive wrist flexion or extension, sustained ulnar deviation, prolonged neck flexion, repetitive typing without scheduled breaks, awkward sitting or lying postures, and prolonged gaming sessions without adequate recovery (AlAbdulwahab et al., 2017). In addition, insufficient physical activity, lack of stretching exercises, poor muscular conditioning, and limited ergonomic awareness further increase the likelihood of developing cumulative trauma disorders affecting the upper extremity (Aalberg et al., 2023). Despite widespread smartphone use among university students, awareness regarding proper smartphone ergonomics remains relatively low, highlighting the need for educational interventions promoting healthier digital device usage practices (Woo et al., 2021).

Table. 2: Major Risk Factors Contributing to Smartphone-Related Hand Musculoskeletal Disorders

Risk Factor	**Mechanism of Effect**	**Possible Musculoskeletal Outcome**
Prolonged smartphone use (>4–6 hours/day)	Increased repetitive loading and reduced tissue recovery	Pain, fatigue, overuse injury
Excessive texting and gaming	Repetitive thumb and finger movements	Thumb pain, tendon irritation
One-handed operation	Increased thumb excursion and force requirement	Thumb and wrist strain
Poor wrist posture	Increased tendon and nerve compression	Wrist pain, neural symptoms
Lack of rest breaks	Reduced recovery and increased muscle fatigue	Reduced endurance and discomfort
Low ergonomic awareness	Incorrect handling techniques	Increased injury risk

Table 2 summarizes the principal behavioral, ergonomic, and individual risk factors associated with smartphone-related hand musculoskeletal disorders among college-going students. Collectively, the available evidence indicates that prolonged smartphone exposure, higher addiction severity, repetitive thumb movements, one-handed operation, poor ergonomic posture, inadequate rest breaks, and reduced awareness of healthy smartphone usage practices act synergistically to increase the occurrence and severity of musculoskeletal symptoms. Early identification of these modifiable risk factors, together with ergonomic education, regular stretching, scheduled rest periods, strengthening exercises, and physiotherapy-guided preventive interventions, may substantially reduce the burden of smartphone-related hand disorders and improve the long-term musculoskeletal health of university students.

6. Assessment of smartphone-related hand disorders in physiotherapy practice:

Physiotherapy assessment is a fundamental component in the identification, diagnosis, and management of smartphone-related hand musculoskeletal disorders among college-going students. A comprehensive assessment enables physiotherapists to identify functional limitations, determine the severity of symptoms, recognize contributing biomechanical and ergonomic factors, and develop individualized rehabilitation programs aimed at restoring hand function and preventing recurrence. Since smartphone-related disorders are multifactorial in nature, assessment should extend beyond pain evaluation to include detailed analysis of smartphone usage behavior, ergonomic practices, musculoskeletal impairments, neural involvement, muscle performance, and functional disability (Demirci et al., 2016). The initial evaluation begins with detailed history taking, which provides valuable information regarding the patient's smartphone usage pattern and symptom progression (Elhai et al., 2017). Clinicians should document the average daily duration of smartphone use, frequency of uninterrupted screen exposure, primary smartphone activities such as texting, gaming, social media browsing, online learning, or video streaming, preferred hand dominance, one-handed or two-handed operation, device size, and typical postures adopted during smartphone use (Cha & Seo, 2018). Information regarding the onset, duration, location, intensity, and progression of symptoms should also be collected, along with aggravating and relieving factors, occupational and academic demands, recreational activities, previous upper-limb injuries, medical history, and any existing musculoskeletal or neurological disorders that may influence symptom presentation (Toh et al., 2017). In addition, assessment of smartphone addiction behavior using standardized tools such as the Smartphone Addiction Scale (SAS) or Smartphone Addiction Scale–Short Version (SAS-SV) helps identify excessive smartphone dependency and establishes the relationship between behavioral patterns and musculoskeletal symptoms (Kwon et al., 2017). Following history taking, pain assessment is essential to determine symptom severity and guide treatment planning (Lee et al., 2018). The Visual Analog Scale (VAS) and Numeric Pain Rating Scale (NPRS) are commonly used, reliable, and valid instruments for quantifying pain intensity associated with smartphone-related disorders (Eitivipart et al., 2018). Detailed pain mapping should identify the exact location of discomfort, whether involving the thumb, radial aspect of the wrist, palm, fingers, forearm, or carpal tunnel region, thereby assisting in differentiating tendon disorders, joint pathology, muscular fatigue, and nerve-related symptoms (Kim et al., 2019). Clinicians should also evaluate pain behavior during functional activities such as texting, gripping, writing, lifting objects, typing, or prolonged smartphone use, as activity-specific pain patterns often provide important diagnostic clues (Neupane et al., 2017). Observation of swelling, tenderness, erythema, muscle guarding, and postural abnormalities further contributes to clinical decision-making (İnal et al., 2018). A comprehensive functional assessment is equally important because smartphone-related musculoskeletal disorders frequently affect the ability to perform daily activities requiring fine motor control and sustained hand function (Xie et al., 2020). Standardized outcome measures such as the Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire and the Patient-Rated Wrist Evaluation (PRWE) provide objective assessment of upper-extremity disability, pain, and functional limitations while enabling clinicians to monitor treatment outcomes over time (Sharan et al., 2020). Additional hand function tests evaluating pinch strength, dexterity, object manipulation, handwriting performance, buttoning, opening containers, carrying objects, and other functional tasks may further identify deficits affecting academic and occupational performance (Berolo et al., 2016). Assessment of range of motion (ROM) of the thumb, fingers, wrist, and forearm should be performed using standardized goniometric techniques to identify movement restrictions, joint stiffness, pain-provoked movements, and compensatory movement patterns (Gustafsson et al., 2017). Muscle performance assessment should include manual muscle testing of the intrinsic hand muscles, thumb musculature, wrist flexors, wrist extensors, and forearm stabilizers to determine strength deficits

associated with repetitive smartphone use (Yeun & Han, 2020). Particular attention should be given to the assessment of hand grip strength, which represents one of the most important objective indicators of overall hand function and muscular performance (Fernández-de-Las-Peñas et al., 2021). Measurement using a calibrated hand dynamometer provides reliable quantitative information regarding muscular strength, endurance, fatigue, and functional impairment while allowing comparison between dominant and non-dominant hands (Samaan et al., 2022). Reduced grip strength among excessive smartphone users may indicate muscle fatigue, tendon dysfunction, pain inhibition, or decreased neuromuscular performance secondary to repetitive loading (Osailan, 2021). Similarly, pinch strength testing using lateral, tip-to-tip, and three-point pinch measurements may identify deficits in precision grip required for writing, laboratory work, and daily functional tasks (AlAbdulwahab et al., 2017). Physiotherapists should also evaluate posture and ergonomic factors, including cervical alignment, shoulder posture, elbow position, wrist angle, thumb reach, forearm support, and smartphone holding techniques during simulated device use, as faulty ergonomics significantly contribute to cumulative tissue stress (Woo et al., 2021). Special clinical tests such as Finkelstein's test for De Quervain's tenosynovitis, Phalen's test, Tinel's sign, and Median Nerve Upper Limb Neurodynamic Test (ULNT1) may be performed when tendon or nerve involvement is suspected (Aalberg et al., 2023). Finally, integrating information obtained from subjective history, pain evaluation, functional outcome measures, grip strength testing, range of motion assessment, muscle performance evaluation, ergonomic analysis, and special orthopedic tests enables physiotherapists to establish an accurate clinical diagnosis, identify modifiable risk factors, and develop individualized evidence-based rehabilitation programs. Comprehensive physiotherapy assessment not only facilitates early detection of smartphone-related hand musculoskeletal disorders but also provides an objective baseline for monitoring treatment effectiveness, improving functional recovery, reducing pain, and preventing long-term disability among college-going students.

7. Physiotherapy management strategies for smartphone-related hand musculoskeletal disorders:

Physiotherapy plays a pivotal role in the prevention, early identification, treatment, and long-term management of smartphone-related hand and wrist musculoskeletal disorders among college-going students, as excessive smartphone use has become one of the leading contributors to repetitive strain injuries affecting the upper extremity (Demirci et al., 2016). With the increasing dependence on smartphones for academic learning, communication, entertainment, and social networking, physiotherapists are increasingly required to address digital device-related overuse conditions using evidence-based assessment and rehabilitation approaches that target both symptom relief and correction of underlying biomechanical dysfunctions (Elhai et al., 2017). The primary objectives of physiotherapy management include reducing pain and inflammation, restoring normal hand and wrist function, improving muscular strength and endurance, enhancing flexibility and joint mobility, correcting faulty movement patterns, promoting ergonomic awareness, and preventing recurrence through behavioral modification and patient education (Cha & Seo, 2018). Effective rehabilitation should not focus solely on symptomatic treatment but should also address the underlying risk factors, including prolonged smartphone exposure, repetitive thumb movements, sustained gripping, poor wrist posture, inadequate rest intervals, reduced physical activity, and improper ergonomic practices that contribute to cumulative tissue loading (Toh et al., 2017). The overall physiotherapy management pathway for smartphone-induced hand disorders is illustrated in Figure 4, which highlights the sequence of clinical assessment, ergonomic correction, therapeutic exercise, manual therapy, and functional rehabilitation required for comprehensive patient management.

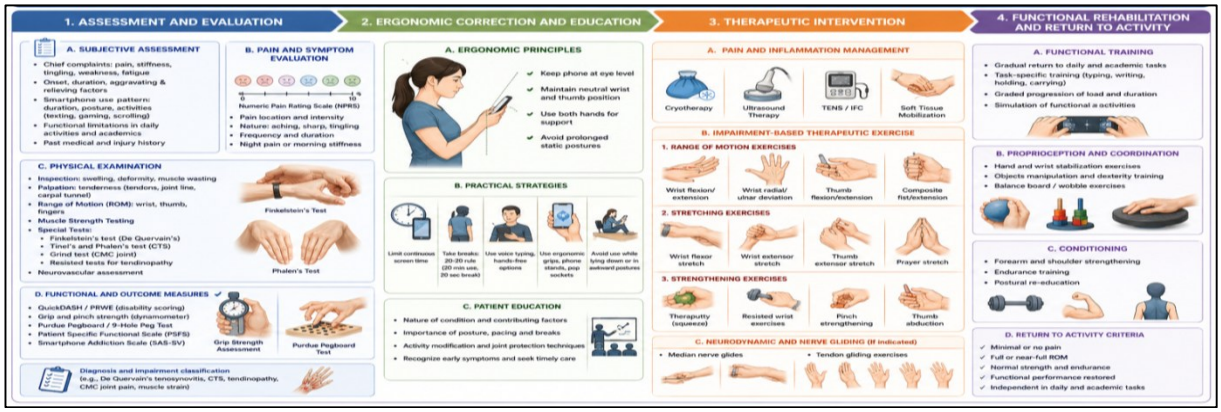

Figure. 4: Physiotherapy assessment and management approach for smartphone-related hand and wrist musculoskeletal disorders involving evaluation, ergonomic correction, therapeutic exercise, and functional rehabilitation

Among all physiotherapy interventions, patient education and ergonomic modification form the cornerstone of both prevention and treatment because many college students remain unaware of the potential musculoskeletal consequences associated with prolonged smartphone use (Lee et al., 2018). Physiotherapists should educate students regarding healthy smartphone habits, emphasizing the importance of maintaining a neutral wrist position, avoiding excessive wrist flexion or deviation, alternating between dominant and non-dominant hands during prolonged smartphone use, and adopting two-handed smartphone operation whenever possible to reduce excessive thumb excursion and mechanical loading (Eitivipart et al., 2018). Students should also be encouraged to hold smartphones closer to eye level to minimize prolonged wrist and cervical flexion, while scheduling regular movement breaks during continuous smartphone use to reduce muscular fatigue and improve tissue recovery (Kim et al., 2019). Incorporating frequent posture changes and modifying the 20-20-20 rule for musculoskeletal health by encouraging short stretching and movement breaks every 20–30 minutes may further reduce cumulative biomechanical stress on the hand and wrist (Neupane et al., 2017). Therapeutic exercise represents one of the most effective evidence-based physiotherapy interventions for restoring muscle performance, flexibility, endurance, and functional capacity following smartphone-related overuse injuries (İnal et al., 2018). Individualized exercise programs should be developed according to symptom severity, clinical findings, pain intensity, and functional limitations while progressively increasing exercise intensity as symptoms improve (Xie et al., 2020). Stretching exercises are recommended to maintain flexibility of the wrist flexors, wrist extensors, thumb musculature, and intrinsic hand muscles, thereby reducing muscle tightness and improving joint mobility (Sharan et al., 2020). Wrist flexor stretching decreases shortening associated with prolonged smartphone holding, whereas wrist extensor stretching improves flexibility of muscles responsible for stabilizing the wrist during repetitive thumb movements (Berolo et al., 2016). Gentle thumb mobility exercises, including opposition, abduction, extension, and circumduction movements, help preserve normal carpometacarpal joint mobility and reduce stiffness resulting from repetitive touchscreen activities (Gustafsson et al., 2017). In addition to flexibility training, progressive strengthening exercises are essential for improving muscular endurance and increasing tolerance to repetitive functional activities (Yeun & Han, 2020). Recommended strengthening exercises include hand-grip training using therapeutic putty or hand exercisers, finger extension exercises with elastic resistance bands, thumb opposition strengthening, wrist flexor and extensor strengthening using light resistance, intrinsic hand muscle activation exercises, and forearm stabilization exercises to improve dynamic control during smartphone use (Fernández-de-Las-Peñas et al., 2021). Strengthening should progress gradually to prevent excessive tendon loading and minimize symptom exacerbation. Patients presenting with neural symptoms such as tingling, numbness, or burning sensations may benefit from neural mobilization techniques, particularly median nerve gliding exercises, which improve neural excursion, reduce mechanosensitivity, and decrease symptoms associated with prolonged wrist positioning (Samaan et al., 2022). Neural mobilization should always be performed under physiotherapeutic supervision to ensure appropriate dosage and avoid symptom aggravation (Osailan, 2021).

Figure. 5: Therapeutic exercises commonly recommended for prevention and rehabilitation of smartphone-associated hand and wrist disorders, including stretching, strengthening, and mobility exercises

In addition to exercise therapy, manual therapy and soft tissue techniques may be incorporated to reduce pain, improve joint mobility, restore soft tissue flexibility, and facilitate functional recovery (AlAbdulwahab et al., 2017). Commonly utilized physiotherapy techniques include soft tissue mobilization, myofascial release, trigger point therapy, tendon-gliding exercises, joint mobilization of the wrist and thumb, and gentle mobilization of the first carpometacarpal and radiocarpal joints to improve arthrokinematics and reduce movement restrictions (Woo et al., 2021). Patients with De Quervain's tenosynovitis or localized tendon irritation may particularly benefit from gentle tendon mobilization combined with progressive loading programs that enhance tissue remodeling while minimizing pain (Aalberg et al., 2023). Splinting and supportive approaches may also provide temporary symptom relief during the acute inflammatory phase of tendon disorders by limiting excessive thumb and wrist movements (Park et al., 2021). Thumb spica splints and neutral wrist braces are commonly prescribed for individuals with De Quervain's tenosynovitis, thumb overuse syndrome, or significant wrist pain to reduce mechanical stress on irritated tissues (Yoon et al., 2020). However, prolonged immobilization should be avoided because it may contribute to joint stiffness, muscle weakness, and delayed functional recovery. Splinting should therefore be combined with structured therapeutic exercises and gradual return to activity (Li et al., 2022). The final stage of rehabilitation involves functional rehabilitation, which aims to restore the individual's ability to perform academic, occupational, and daily activities without pain or functional limitation (Rahman et al., 2024). Functional rehabilitation programs should include handwriting practice, fine motor coordination exercises, object manipulation tasks, grip endurance training, dexterity activities, simulated academic tasks, and gradual return-to-study modifications based on symptom tolerance (Sohn et al., 2019). Students should also be educated regarding balanced digital device usage, incorporation of regular physical activity, scheduled movement breaks, ergonomic workstation setup, and healthy movement habits to minimize recurrence of smartphone-related musculoskeletal disorders. Through comprehensive physiotherapy management integrating patient education, ergonomic correction, therapeutic exercise, neural mobilization, manual therapy, supportive splinting, and functional rehabilitation, clinicians can effectively reduce pain, improve hand performance, restore functional independence, and promote long-term musculoskeletal health among college-going students with smartphone-related hand and wrist disorders.

8. Preventive role of physiotherapy in digital device users:

The increasing prevalence of smartphone-related hand and wrist musculoskeletal disorders among college-going students highlights the growing need for preventive physiotherapy strategies aimed at reducing the burden of repetitive strain injuries before they become chronic and functionally disabling (Demirci et al., 2016). Unlike many occupational musculoskeletal disorders that develop after prolonged workplace exposure, smartphone-associated conditions are largely preventable through early identification of risk factors, ergonomic modification, behavioral interventions, and health education promoting safe digital device usage (Elhai et al., 2017). Physiotherapists play a central role in primary prevention by educating students about appropriate smartphone handling techniques, encouraging healthy movement habits, and promoting awareness of the musculoskeletal consequences of prolonged smartphone dependency (Cha & Seo, 2018). Educational programs should emphasize

maintaining a neutral wrist position, minimizing excessive thumb excursion, avoiding prolonged one-handed smartphone operation, alternating hands during extended device use, and incorporating regular movement breaks to reduce cumulative mechanical loading on the hand and wrist (Toh et al., 2017). The implementation of campus-based ergonomic awareness programs can substantially improve students' understanding of proper posture, optimal smartphone positioning, and effective self-management strategies to minimize repetitive strain injuries (Lee et al., 2018). In addition, screening programs conducted by physiotherapists may help identify students at high risk of developing musculoskeletal disorders by assessing smartphone addiction levels, daily usage duration, ergonomic habits, pain symptoms, grip strength, posture, and functional limitations before significant disability develops (Eitivipart et al., 2018). Early screening enables timely intervention and individualized preventive exercise programs, thereby reducing the progression of minor symptoms into chronic tendon or nerve disorders (Kim et al., 2019). Regular smartphone usage education sessions should also be incorporated into university health promotion initiatives to encourage balanced digital device use, scheduled rest intervals, appropriate workstation setup, and increased participation in physical activity (Neupane et al., 2017). Physiotherapists can further organize exercise workshops focusing on stretching, strengthening, tendon-gliding exercises, neural mobility, posture correction, and hand-conditioning exercises designed to improve muscular endurance and reduce tissue fatigue associated with repetitive smartphone use (İnal et al., 2018). Development of digital health guidelines for educational institutions may provide evidence-based recommendations regarding maximum daily smartphone exposure, appropriate break schedules, ergonomic principles, and preventive exercise routines to promote long-term musculoskeletal health among students (Xie et al., 2020). Since lifestyle habits established during early adulthood frequently persist throughout later life, preventive interventions implemented during the college years have the potential to reduce future musculoskeletal morbidity, improve functional capacity, and encourage lifelong healthy technology use (Sharan et al., 2020). Figure 6 illustrates the major ergonomic strategies recommended for preventing smartphone-related hand musculoskeletal disorders, including maintaining correct posture, reducing repetitive thumb strain, optimizing smartphone positioning, alternating hands during prolonged use, and incorporating regular movement breaks to minimize cumulative biomechanical stress on the upper extremity.

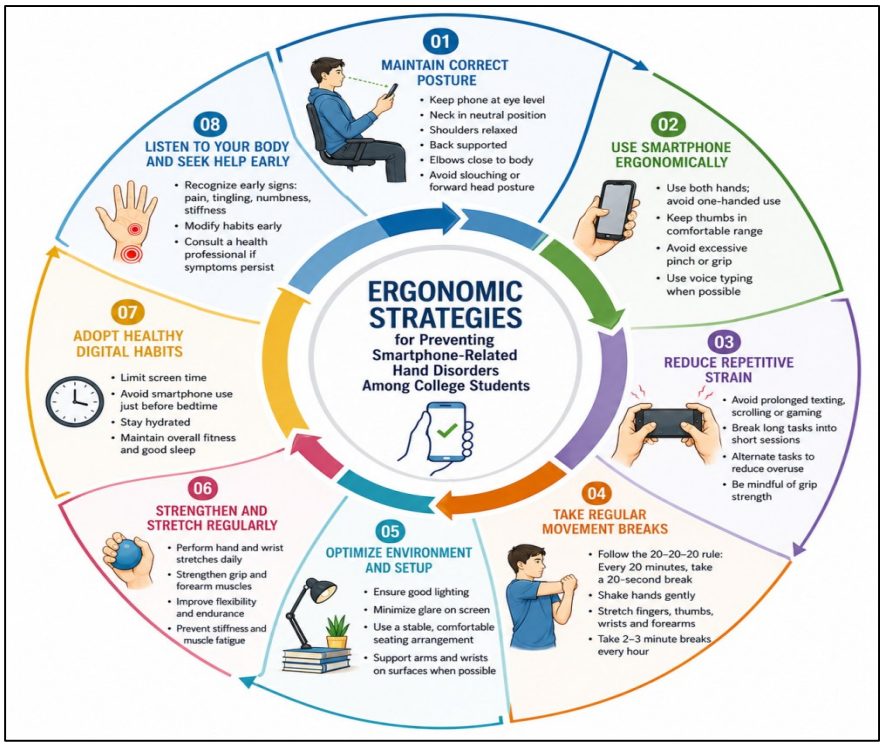

Figure. 6: Ergonomic strategies for preventing smartphone-related hand disorders among college students, including correct posture, reduced repetitive strain, and regular movement breaks

9. Impact of smartphone addiction on quality of life and academic performance:

Smartphone addiction has significant consequences beyond physical discomfort, affecting the overall quality of life, functional independence, academic performance, and psychosocial well-being of college-going students (Demirci et al., 2016). As smartphones have become integral to education, communication, and daily living, excessive and repetitive smartphone use has increased the prevalence of hand and wrist musculoskeletal disorders that may interfere with routine functional activities and reduce overall productivity (Elhai et al., 2017). Persistent hand pain, thumb discomfort, wrist stiffness, muscle fatigue, reduced grip strength, and impaired dexterity can adversely affect students' ability to perform essential academic tasks, including note-taking, prolonged handwriting, computer usage, typing assignments, laboratory experiments, clinical skill training, and practical examinations that require precise hand movements (Cha & Seo, 2018). Students experiencing chronic hand symptoms often report difficulty maintaining prolonged writing posture, carrying books or laboratory equipment, opening containers, manipulating small instruments, and performing fine motor activities necessary for educational and professional development (Toh et al., 2017). In addition to academic limitations, smartphone-related hand disorders may negatively influence participation in sports, recreational activities, musical performance, hobbies, and routine self-care activities such as dressing, grooming, cooking, and household tasks that depend on adequate grip strength and manual dexterity (Lee et al., 2018). Continuous pain and functional limitations frequently reduce confidence in hand use, resulting in activity avoidance, decreased physical performance, and reduced participation in social and recreational events (Eitivipart et al., 2018). As symptoms persist, students may experience declining academic productivity, difficulty completing assignments on time, impaired concentration, and reduced learning efficiency due to discomfort associated with prolonged smartphone and computer use (Kim et al., 2019). Chronic musculoskeletal pain has also been associated with psychological consequences, including increased stress, anxiety, frustration, reduced motivation, and lower health-related quality of life, particularly among young adults facing continuous academic demands (Neupane et al., 2017). The relationship between smartphone addiction and musculoskeletal disorders is further complicated by prolonged sedentary behavior, as excessive screen time often replaces participation in physical exercise, outdoor recreation, and fitness activities that are essential for maintaining musculoskeletal health (İnal et al., 2018). Reduced physical activity contributes to generalized muscle weakness, decreased flexibility, poor postural control, impaired cardiovascular fitness, and increased susceptibility to additional musculoskeletal disorders involving the neck, shoulders, upper back, and spine (Xie et al., 2020). Consequently, students with smartphone addiction frequently present with multiple concurrent musculoskeletal complaints rather than isolated hand symptoms, reflecting the widespread biomechanical effects of prolonged digital device use (Sharan et al., 2020). Persistent discomfort may also disturb sleep quality and delay tissue recovery, further increasing fatigue and reducing functional capacity during academic and recreational activities (Berolo et al., 2016). From a physiotherapy perspective, early recognition and management of smartphone-related hand disorders are essential for preserving functional independence, improving academic performance, restoring participation in recreational activities, and preventing long-term disability (Gustafsson et al., 2017). Comprehensive rehabilitation programs incorporating ergonomic education, posture correction, therapeutic exercises, strengthening, stretching, activity modification, and behavioral interventions can significantly improve hand function, reduce pain, and enhance quality of life among college-going students (Yeun & Han, 2020). Furthermore, promoting balanced smartphone use, encouraging regular physical activity, implementing scheduled movement breaks, and increasing awareness regarding healthy digital habits are important strategies for minimizing the functional and psychosocial consequences of excessive smartphone dependency (Fernández-de-Las-Peñas et al., 2021). Figure 7 illustrates the conceptual relationship between smartphone addiction, repetitive mechanical loading of the hand and wrist, development of musculoskeletal disorders, progressive functional impairment, and the subsequent impact on academic performance, physical activity, and overall quality of life among college-going students.

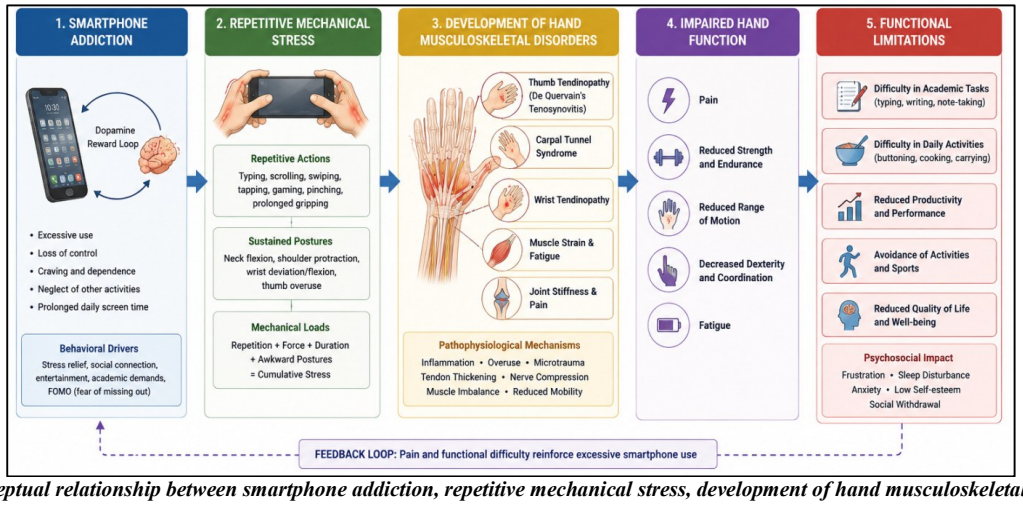

Figure.7: Conceptual relationship between smartphone addiction, repetitive mechanical stress, development of hand musculoskeletal disorders, and functional limitations

10. Future research perspectives:

Although current evidence indicates a significant association between excessive smartphone use and the development of hand and wrist musculoskeletal disorders among college-going students, additional high-quality research is required to establish stronger causal relationships and develop evidence-based clinical guidelines for prevention and rehabilitation (Demirci et al., 2016). Future investigations should prioritize longitudinal cohort studies to evaluate the long-term effects of prolonged smartphone exposure on hand function, tendon health, muscle performance, and the progression of musculoskeletal symptoms over time (Elhai et al., 2017). Advanced biomechanical analyses using motion capture systems, wearable sensors, electromyography, and pressure-mapping technologies are needed to objectively quantify thumb movements, grip forces, wrist posture, and tissue loading during different smartphone activities (Cha & Seo, 2018). Researchers should also establish standardized diagnostic criteria and validated clinical assessment protocols for smartphone-related hand musculoskeletal disorders to improve consistency across epidemiological and clinical studies (Toh et al., 2017). Randomized controlled trials evaluating the effectiveness of physiotherapy-led prevention programs, ergonomic interventions, structured exercise protocols, and educational strategies are essential to determine the most effective approaches for reducing smartphone-related musculoskeletal symptoms (Lee et al., 2018). Furthermore, the development of evidence-based smartphone ergonomic guidelines and the integration of wearable technologies capable of monitoring hand posture, repetitive movements, and cumulative mechanical loading may facilitate early detection of overuse injuries and encourage healthier digital habits among students (Fernández-de-Las-Peñas et al., 2021). Future research should also investigate whether reducing daily smartphone exposure, modifying usage behavior, increasing movement breaks, and improving ergonomic practices can reverse early musculoskeletal changes and prevent the progression of chronic hand disorders in young adults (Samaan et al., 2022).

11. Limitations of current evidence:

Despite the growing body of literature investigating smartphone-related hand musculoskeletal disorders, several important limitations continue to restrict the interpretation and generalizability of existing evidence (Demirci et al., 2016). A major limitation is the widespread reliance on self-reported questionnaires for assessing smartphone usage duration, addiction severity, and musculoskeletal symptoms, which may introduce recall bias, reporting bias, and subjective variability in outcome measurement (Elhai et al., 2017). Furthermore, considerable heterogeneity exists in the methods used to quantify smartphone exposure, including differences in screen-time estimation, addiction scales, and symptom assessment tools, making direct comparison and meta-analysis across studies challenging (Cha & Seo, 2018). Most available investigations are cross-sectional in design and therefore identify associations rather than establishing causal relationships between excessive smartphone use and hand musculoskeletal disorders (Toh et al., 2017). In addition, many studies emphasize symptom prevalence instead of incorporating objective clinical assessments such as grip strength testing, imaging, electromyography, biomechanical analysis, or standardized physiotherapy evaluation protocols (Lee et al., 2018). The majority of published research has been conducted among university students from limited geographical regions using

relatively small sample sizes, thereby reducing the external validity and global applicability of the findings (Xie et al., 2020). Finally, there remains a shortage of well-designed randomized controlled trials evaluating physiotherapy interventions, ergonomic modification programs, and long-term rehabilitation outcomes, highlighting the need for stronger evidence to establish standardized, evidence-based management strategies for smartphone-related hand musculoskeletal disorders (Fernández-de-Las-Peñas et al., 2021).

12. Conclusion:

Smartphone addiction has emerged as an important lifestyle-related factor contributing to hand and wrist musculoskeletal complaints among college-going students. Excessive smartphone use involves repetitive thumb movements, prolonged gripping, and sustained wrist postures that may increase mechanical stress on muscles, tendons, joints, and neural structures. Commonly reported conditions include thumb pain, De Quervain's tenosynovitis, wrist discomfort, tendon overuse injuries, nerve-related symptoms, and reduced grip strength. College students represent a high-risk population due to their extensive dependence on smartphones for academic and social activities. Physiotherapy plays a significant role in addressing these emerging digital-age musculoskeletal problems through assessment, ergonomic correction, therapeutic exercises, manual therapy, and preventive education. Promoting healthy smartphone habits and incorporating physiotherapy-based interventions can help maintain optimal hand function and reduce the burden of smartphone-associated disorders.

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