Airborne or droplet precautions for health workers treating COVID-19?

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Summary: At present, the limited available evidence does not support droplet precautions and 1 – 2 m (≈3 – 6 ft) rule of special separation being adequate for occupational health and safety of health workers treating patients with COVID-19.

Abstract

Cases of COVID-19 have been reported in over 200 countries. Thousands of health workers have been infected and outbreaks have occurred in hospitals, aged care facilities and prisons. World Health Organization (WHO) has issued guidelines for contact and droplet precautions for Healthcare Workers (HCWs) caring for suspected COVID-19 patients, whilst the US Centre for Disease Control (CDC) has recommended airborne precautions. The 1 – 2 m (≈3 – 6 ft) rule of spatial separation is central to droplet precautions and assumes large droplets do not travel further than 2 m (≈6 ft). We aimed to review the evidence for horizontal distance travelled by droplets and the guidelines issued by the World Health Organization (WHO), US Center for Diseases Control (CDC) and European Centre for Disease Prevention and Control (ECDC) on respiratory protection for COVID-19. We found that the evidence base for current guidelines is sparse, and the available data do not support the 1 – 2 m (≈3 – 6 ft) rule of spatial separation. Of ten studies on horizontal droplet distance, eight showed droplets travel more than 2 m (≈6 ft), in some cases more than 8 meters (≈26 ft). Several studies of SARS-CoV-2 support aerosol transmission and one study documented virus at a distance of 4 meters (≈13 ft) from the patient. Moreover, evidence suggests infections cannot neatly be separated into the dichotomy of droplet versus airborne transmission routes. Available studies also show that SARS-CoV-2 can be detected in the air, 3 hours after aeroslisation. The weight of combined evidence supports airborne precautions for the occupational health and safety of health workers treating patients with COVID-19.

Keywords: Droplet Transmission, Respiratory Protection, Coronavirus, Mask, SARS-CoV-2, COVID-19

Text

The epidemic of COVID-19 was reported to the World Health Organization on December 31 2019 [1], with the number of confirmed cases remaining around 40 – 60 until January 20th 2020, when a surge of cases occurred, possibly associated with increased domestic and international travel in China for the Lunar New Year celebration. On January 30th 2020, number of cases surged to surpass SARS, with cases spreading to over 28 other countries, mostly through travel from China [2]. On March 11, 2020 with more than 118,000 cases spread across 114 countries and 4,291 deaths, it was recognized as a pandemic by WHO [1].

Coronaviruses are respiratory pathogens, and the SARS-CoV-2 has been identified in both upper and lower respiratory tract samples from patients [3]. Fever, dry cough, malaise, lethargy, shortness of breath, myalgia are the commonest symptoms [2]. Less common symptoms are headache, productive cough and diarrhoea. Mild cases may present with a common cold like syndrome, whilst severe cases may develop severe acute respiratory distress syndrome and pneumonia. According to the WHO 21% of cases in China have a severe illness [2]. Early estimates of the reproduction number, R_0, give values around 2.2 with a mean incubation period of 5.2 days [4], and a range up to 24 days. A review found the average R_0 value for COVID-19 to be up to 3.28 and median value to be around 2.79 [5]. A more recent study estimated the Maximum-Likelihood (ML) value of R_0 to be 2.28 for the Diamond Princess cruise ship [6]. All these estimates are similar to R_0 estimates for SARS [7].

In the past epidemics of SARS and MERS Coronavirus, health care workers (HCWs) have paid a heavy toll. During SARS, HCWs comprised 21% of all cases and in some countries, such as Hong Kong, Singapore and Canada, more than half the cases were HCWs, with deaths reported among them [8]. HCW deaths have already been reported with COVID-19.

The WHO has issued guidelines for protection of HCWs which recommend contact and droplet precautions for HCWs caring for suspected COVID-19 patients [9]. Specifically, a medical mask is recommended for routine care, while a respirator (airborne precautions) is recommended if HCWs are conducting an aerosol-generating procedure such as endotracheal intubation, bronchoscopy or airway suctioning, along with droplet precautions [9]. Droplet precautions includes the recommendation to maintain spatial separation of 1 m (≈3 ft) with an infected patient, in the belief that large droplets can only spread horizontally to a maximum of 1 m (≈3 ft) [10]. The initial guidelines released by US Centers for Disease Control recommended a more precautionary approach, which includes the use of a mask by the patient (source control [11]), and airborne precautions for HCWs [12].

We aimed to review the evidence supporting the rule of 1 m (≈3 ft) spatial separation for droplet precautions in the context of guidelines issued by the World Health Organization (WHO), US Center for Diseases Control (CDC) and European Centre for Disease Prevention and Control (ECDC) for HCWs on respiratory protection for COVID-19.

Methods

A systematic review was conducted for evidence of horizontal distance travelled by respiratory droplets, using the PRISMA criteria [13]. We used an open date strategy up to March 2020 for searching the literature. The search was made on PubMed and Scopus database and the search terms used for literature search are, (cough OR sneeze AND droplet AND spread) OR (cough OR sneeze AND droplet AND distance).

There are few studies on horizontal spread of droplets in medical journals, so we included original research studies from various science and engineering disciplines, including mathematical, numerical and experimental studies, published in English language journals. We searched Scopus database with same keywords and date strategy for studies published in non-medical journals. Editorials and reviews were excluded from the review.

Initial screening of articles was done by one reviewer (PB). For initial screening, the title and abstract of all the articles were reviewed. Articles were excluded if there is no information on droplet spread. All the articles that were potentially relevant after initial screening were procured in full text. Articles were included for the final review only if it specifically measured the horizontal distance of droplet spread. References of the papers were also included for screening if they fit the inclusion criteria. Four reviewers with expertise in fluid dynamics (PB, CD, CDS, LB) reviewed the selected articles.

For the review we focused on the following 4 variables among the studies included,

1. Type of study – Experimental or Modeling.
2. Methodology employed for modeling.
3. Use of human subjects for data.
4. Data on extent of horizontal spread.

Separate to review of original research evidence for horizontal spread of droplets, the guidelines for respiratory protection issued by the World Health Organization (WHO), US Centre for Disease Control (CDC) and European Centre for Disease Prevention and Control (ECDC) for SARS, MERS and COVID-19 coronaviruses were reviewed.

Results

We found 393 papers in the initial search. After reviewing the titles and abstracts 28 papers were selected for full text review. Finally, 10 papers were included in the review (Figure 1).

Eight of the ten studies discussed a horizontal trajectory greater than 2 m (≈6 ft) for a range of droplet sizes of less than 60 µm [14–21]. Seven out of ten studies are based on modelling and among them the extent of horizontal spread of droplets vary between 2 – 8 m (≈6 – 26 ft) [14–20], highlighting differing findings between them, which can be partially attributed to the methodologies employed. Specifically, four of these studies rely on computational fluid dynamics (CFD) approaches that do not account accurately for the multiphase particle-flow interaction physics [14,15,18,20] and three of them model cough as a turbulent jet (continuous ejection with conservation of momentum flux) instead of a turbulent puff (short sudden ejection with conservation of momentum) [15,18,20]. The fourth study used Lagrangian modelling for the droplet dispersion and it was acknowledged that this approach assigns a larger momentum to air hence, making it difficult to translate the results into relevant settings for hospital infection control [14].

Two studies used analogous water tank experiments to validate the mathematical modelling developed and reported distances up to 1.4 m (≈4.5 ft) and 2.5 m (≈8.2 ft) [17,22]. One of these two studies modelled coughs as turbulent jets (continuous emission) [22] despite contrary evidence showing that the physics of violent exhalations is captured by puffs, sudden high momentum emission of moist and hot air [17].

Five studies performed experiments on human subjects[14,17,19,21,23], four of them generated undisturbed/natural sneezes and coughs, without injestion of fluid or powders by the human subjects [17,19,21,23]. Out of five, two studies used the human subject measurements to develop and validate the mathematical modelling of the droplet dispersal and showed the importance of the exhaled gas cloud of hot and moist air in trapping and extending the range of all droplets [17,19]. One involved injection of powder in the mouth of the human subject potentially shifting the natural droplet sizes ejected [14]. The other two used still photographs [23] and particle counters [21] and the distance reported among these two vary from 1 – 3 m (≈3 – 10 ft). Table 1 summarises all the findings and figure 2 shows the horizontal distance of droplet spread reported by all the studies.

Table 2 summarises the respiratory protection guidelines by WHO, CDC and ECDC for SARS, MERS CoV and COVID-19. Guidelines differentiates between high-risk and low-risk situations. High-risk is categorized as situations involving an aerosol generating procedure i.e., endotracheal intubation, bronchoscopy, open suctioning, administration of nebulized treatment, manual ventilation before intubation, turning the patient to the prone position, disconnecting the patient from the ventilator, non-invasive positive-pressure ventilation, tracheostomy, and cardiopulmonary resuscitation. All other situations are considered low risk. The WHO and CDC recommends respirators to protect from SARS in both low and high-risk situations [24,25]. For MERS WHO recommends masks in low-risk situations and respirators in high-risk situations, CDC recommends respirators in both situations and ECDC recommends a pre-assessment of workplace to decide between mask and respirator in low-risk situations and respirators for high-risk situations [26–28]. For COVID-19 WHO recommends masks in low-risk situations and respirators in high-risk situations. The CDC and ECDC initially recommended respirators in both situations, but after PPE shoratges, CDC downgraded to use of masks in low risk situations and ECDC recommended use of mask in case of non-availability of respirators [29–31].

The interim guidelines for COVID-19 appear to assume only droplet and contact spread and the general risk limit defined for healthcare workers is 1 m (≈3 ft) from the patient [10,31].

Discussion

The transmission of COVID-19 is not well characterised, but is likely to be similar to SARS, which was spread by contact, droplet and airborne routes [32]. Given the presence of SARS-CoV-2 viral loads in both the lower and upper respiratory tract[3], as well as persistence of the virus in the air 3 hours after aeroslisation [33], airborne transmission is possible. A recent study showed that seasonal coronaviruses were more commonly emitted in aerosols than in droplets, even through normal tidal breathing [34]. It is timely to review the evidence informing the 1 – 2 m (≈3 – 6 ft) rule of infection control, which drives guidelines for droplet precautions. Most studies of horizontal transmission of droplets show distances of greater than 2 m (≈6 ft). The maximum distance recorded in the few available studies is 8 m (≈26 feet) [19,35]. We note, although the studies employed very different methodologies and should be interpreted cautiously, they still confirm that the spatial separation limit of 1 m (≈3 ft) prescribed for droplet precautions, and associated recommendations for staff at ports of entry [10], are not based on current scientific evidence.

The horizontal distance of droplet spread depends on various factors such as viscoelasticity of the expiration fluid, type of ventilation, velocity of expiration, rate of evaporation and the dynamics of turbulent cloud generated during exhalations, sneezing, or coughing [15,17–19]. The 1 – 2 m (≈3 – 6 ft) limit is based on very limited epidemiologic and simulated studies of some selected infections [36]. Some studies cite Jennison (1942) [23] as the evidence in support of the 1 – 2 m (≈3 – 6 ft) risk limit. This study used high speed exposure to capture still photographs of the atomising secretions generated by human sneezing, coughing and talking, imaged very close to the mouth. It was concluded that the distance to which the majority of droplets were expelled is 2 – 3 ft (≈1 m) but, no details were provided about how they reached this conclusion. The study acknowledges that the motion picture film used for the experiments was not sensitive enough to capture all the droplets. The lighting technique used inherently selects for the largest sizes of droplets and fluid ligaments, not capturing the rest of the emissions and gas cloud carrying them. The author used still photographs, in which many droplets move out of focus and become unrecordable very quickly, especially using photographic technology from the 1940s. More recent studies have shown the extent of droplet spread to be greater than 2 m (≈6 ft) [16–21,35], and that infection risk exists well beyond the recommended range of spatial separation.

Further, there is no agreement on the definition of "droplet" route of transmission. There is some agreement that particles with diameters less than 5 µm are airborne particles but, there is significant variation in the literature when it comes to the classification of the lower size limit of droplets. Wells (1934) [37] considered 100 µm as the cut-off limit for the droplet route. But, later studies considered a cutoff particle diameter of more than 10 µm to more than 100 µm [14,15,20]. The World Health Organization (WHO) employs a cut off limit of 5 µm to differentiate between aerosols (≤5 µm) and droplet (>5 µm) [38] transmission routes. However, even particles with a diameter of more than 10 µm can remain airborne long enough to not fall under the framework of classification of "droplet" route [39]. In addition, the size of a droplet is dynamic and changes within seconds during the transit from the respiratory tract to the environment due to evaporation [39]. A large droplet expelled during coughing or sneezing can become an airborne particle in less than a second [39] and that timescale changes depending on the cloud dynamics of exhalation [17,19]. Hence, it is not possible to characterize droplet and airborne spread as separate, mutually exclusive modes of transmission and further studies of the risks accounting for combined ambient conditions and patient exhaled cloud are needed.

Indeed, another important consideration is the effect of temperature, relative humidity, ventilation etc. on the extent of droplet spread which has been examined by only a few studies. To summarise, they have shown that relative humidity plays an important role in the evaporation of the droplets and the distance a droplet can travel. They report that as the relative humidity increases the extent of droplet spread decreases [18,20], yet the horizontal range of the cloud propelling the drops was found to increase with increase in relative humidity, due to the role of buoyancy of the exhaled cloud [17]. For droplets less than 20 µm in diameter, local airflow field due to body heat is an important factor in determining the extent of spread since it can lift the droplets upwards into the breathing zone [40]. Studies have also shown that depending on the flow direction and airflow pattern, increasing ventilation rate can effectively reduce the risk of long range airborne transmission [41]. Most patients spend the majority of time in normal breathing and can saturate the room air with airborne particles expelled during breathing. Moreover, despite negative pressure isolation conditions, airflow due to door motion can cause breakdown in isolation conditions and as a result pathogen can escape the room and there is probability of infection spread outside the room [42]. In general recent studies show distances reached by potentially pathogen-laden droplets of a continuum of sizes to be far greater than 2 m (≈6 ft) [16–20], therefore the probability of infection well beyond the defined risk limit can be significant. For example, SARS was classified as predominantly transmitted through contact and droplet modes, but, aerosolised transmission well beyond 2 m (≈6 ft) was reported in the Amoy Gardens outbreak [32].

The ability of countries to respond effectively depends on the safety and confidence of the health workforce, especially in low income countries with low ratios of HCWs per head of population and protective measures are crucial to ensure a functional health workforce. We have previously shown that masks do not have clinical efficacy against respiratory infections [43,44], and that intermittent use of respirators (which depends on HCWs to assess their own risk and use the device when they judge they are at risk) is as equally ineffective as mask use [44]. A recent trial confirmed there is no difference between targeted respirator use and surgical mask use, but did not have a control arm and so may have shown equal efficacy or inefficacy [45]. Proven efficacy of a respirator is seen when the device is worn continually during the shift [43]. The SARS-CoV-2 has been found in both upper and lower respiratory tract specimens, often early in the upper and later in the lower respiratory tract [3], which means it can potentially be dispersed in fine, airborne particles. Influenza studies show that in a busy emergency department or hospital ward, airborne particles with viable virus can persist for hours in the air [46]. A study of SARS-CoV-2 in a hospital in Wuhan found virus at least 4 m (≈13 ft) within a hospital ward, and virus was identified in air samples and on multiple air outlet vents [47]. Other studies have also found SARS-CoV-2 on air vents in a patient room [48]. Another study found virus in air samples three hours after aersolisation [33]. We have also shown that airborne precautions are more efficacious in protecting HCWs even against infections assumed to be spread by the droplet route [49]. This further supports the conclusion that infections cannot be neatly separated into droplet versus airborne transmission routes, and that it is likely both airborne and large droplets, carried by the respiratory cloud, are emitted close to the patient and further away. In light of the lack of definitive transmission data for SARS-CoV-2 , as well as persistence of the virus in the air 3 hours after aeroslisation [33], the precautionary principle in the initial CDC guidance was justified. This includes use of a mask by the patient, for which the limited evidence is supportive [11]. Guidelines should be precautionary in ensuring protection of the occupational health and safety of health workers treating COVID-19 [50]. Although the majority of the studies reviewed point towards horizontal spread of more than 2 m (≈6 ft), these results cannot be translated directly to hospital settings, as the studies used varying range of assumptions. The recent data on SARS-CoV-2 in a hospital ward shows a distance travelled by the virus of at least 4 m (≈13 ft), double the assumed safe distance [47]. This review reveals the limited scientific data to inform spatial separation guidelines, and a growing body of evidence that droplet precautions are not appropriate for SARS-CoV-2. Hence, future works on carefully documenting and studying the mechanisms shaping transmission distances are warranted, particularly with experiments over a large number of subjects and a variety of conditions, to update current spatial separation guidelines and the current paradigm of droplet and airborne respiratory transmission routes.

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Table 1: Summary of studies on horizontal spread of droplets

Author (Year)	**Type of Study**	**Type of Experiments**	**Type of Modelling**	**Use of human subjects (Number of Subjects)**	**Main Findings regarding Horizontal Distance**
Jennison (1942)	Experimental	High-speed illumination for still photography	NA	Yes (Not Specified)	Majority of respiratory droplets, generated during sneezing, coughing and talking, are expelled within 1 m (≈3 ft), the size of the filed of observation.
Zhu et al. (2006)	Experimental and Modelling	Particle Image Velocimetry	Numerical Modelling	Yes (3)	More than 6.7 mg of saliva was expelled during coughing, at a maximum velocity of 22 m/s during each cough, affecting even area more than 2 m (≈6.5 ft) away from source.

Xie et al. (2007)	Modelling	NA	Numerical Modelling	No	Expelled large droplets (>60 µm) can travel more than 6 m (≈20 ft) for sneezing with an exhalation velocity of 50 m/s and more than 2 m (≈6.5 ft) for coughing at an exhalation velocity of 10 m/s.
Parienta et al. (2011)	Modelling	NA	Mathematical Modelling	No	With a coughing velocity of 11.7 m/s droplets with a diameter of 16 µm can travel a distance more than 7 m (≈23 ft).
Bourouiba et al. (2014)	Experimental and Modelling	High-speed videography of human subject exhalations; Water tank physical experiments for model validation.	Mathematical Modelling	Yes (Not Specified)	Droplets expelled during sneezing and couching travel within a turbulent gas cloud and examples of ranges, such as that of particle with 30 µm diameter which can have a horizontal range of 2.5 m (≈8 ft).

Wei and Li (2015)	Modelling	NA	Numerical Modelling	No	Relative Humidity (RH) plays an important role in the evaporation of the droplets and the distance a droplet can travel. At a RH of 80% and expiration velocity of 10 m/s, 95% of medium droplets (50 μm) were able to travel 4 m (≈13 ft).
Bourouiba (2016)	Experimental and Modelling	High-speed Video	Mathematical Modelling	Yes (Not Specified)	The smaller and evaporating droplets are trapped in the turbulent cloud, remain suspended, and can travel up to 6 to 8 m (≈20 – 26 ft). Based on modelling validated in Bourouiba et al. (2014).

Wei and Li (2017)	Experimental and Modelling	Water tank model	Mathematical Modelling	No	Scaling relationships were used to scale the results of experiments in water with that of air. With mouth opening of 2 cm, large particles (96 µm) can travel a distance up to 1.4 m (≈4.5 ft).
Liu et al. (2017)	Modelling	NA	Numerical Modelling	No	At 0% RH, 60 µm droplets would dry out and become droplet nuclei with a diameter of 19 µm and could fall out of the jet to reach a distance more than 4 m (≈13 ft).
Lee et al. (2019)	Experimental	Optical particle spectrometer	NA	Yes (10)	Particle sizer and Optical particle spectrometer were used to measure cough particle concentration of 10 patients with cold symptoms in real time. Results showed that transmission can spread more than 3 m (≈10 ft) from the patient.

Table 2: The use of masks/respirators for coronaviruses – recommendations from WHO, CDC and ECDC

Pathogen	**WHO**		**CDC**		**ECDC**	
	Low risk	**High risk**[1]	**Low risk**	**High risk**	**Low risk**	**High risk**
Severe Acute Respiratory Syndrome Coronavirus (SARS-CoV)	Respirator[2]	Respirator	Respirator	Respirator	-	-
Middle East respiratory Syndrome Coronavirus (MERS-CoV)	Mask	Respirator	Respirator	Respirator	Mask/Respirator[3]	Respirator
Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2)	Mask	Respirator	Mask	Respirator	Mask/Respirator[4]	Respirator

[1] High risk are the situations involving an aerosol generating procedure i.e., endotracheal intubation, bronchoscopy, open suctioning, administration of nebulized treatment, manual ventilation before intubation, turning the patient to the prone position, disconnecting the patient from the ventilator, non-invasive positive-pressure ventilation, tracheostomy, and cardiopulmonary resuscitation.

[2] N/R/P 95/99/100 or FFP 2/3 or an equivalent national manufacturing standard (NIOSH (N,R,P 95,99,100) or European CE EN149:2001(FFP 2,3) and EN143:2000 (P2) or comparable

[3] No clear recommendation. Choice is based on the type of exposure risk defined after pre-assessment of workplace.

[4] Healthcare workers in contact with a suspected or confirmed COVID-19 case should wear a surgical mask or, if available an FFP2 respirator tested for fitting.

Figure Legends

Figure 1: Flow diagram of literature search

Figure 2: Extent of horizontal spread of droplets. M: Modelling (mathematical or numerical) studies; E: Experimental studies; H: Human subjects

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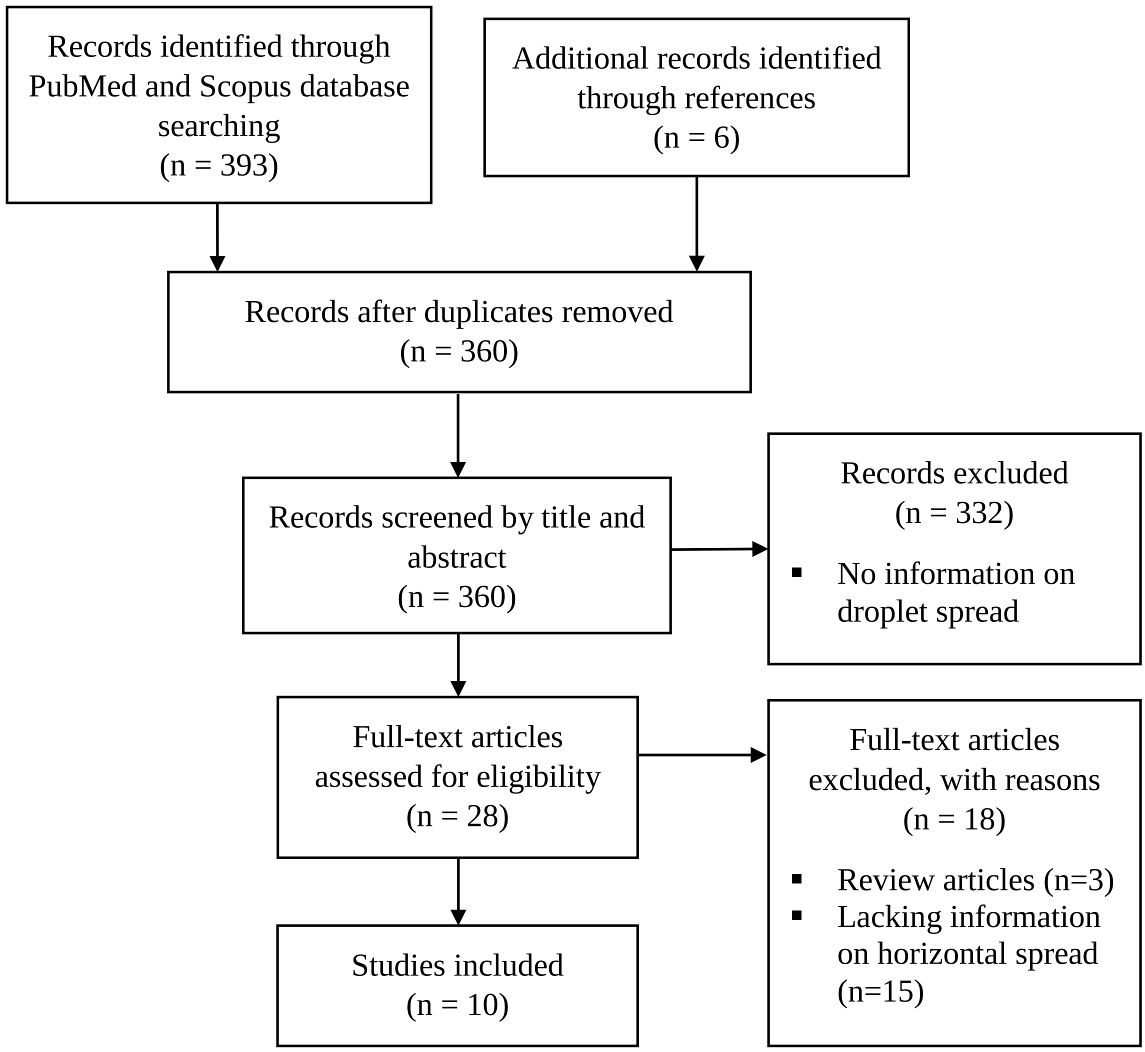

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