Vulnerability of the medical product supply chain: the wake-up call of COVID-19

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INTRODUCTION

The COVID-19 pandemic has brought the long-standing vulnerability of the medical product supply chain into sharp focus. Global shortages of medical products accompanied the global spread of the disease, joined by high prices, the proliferation of suspect dealers and dramatic interventions by governments, philanthropy and industry in oftentimes-unsuccessful attempts to secure solutions.

Much attention has focused on personal protective equipment (PPE). But reported shortages have extended much further—to testing supplies, dialysis materials, pharmaceuticals and a wide range of commodities essential for daily care delivery—both for patients with and without COVID-19.[1 2]

PPE shortages have received particular attention because they endanger the healthcare workforce.[3] But *all* product shortages endanger patients due to delays in care, rationing or denial of care, the use of substandard products, or heightened risk of error when using replacement products—risks that extend to increased mortality.[4] Medical product shortages threaten the goal to deliver the right care to the right person at the right time—and have done so for decades.[5] The COVID-19 pandemic has highlighted more than ever that these systemic risks can no longer be ignored. It may also mean that new solutions have become more possible.

Why care about medical supply chains?

Unexpected shortages of medical products do not fit neatly into any single quality domain, but can affect all of them. We cannot provide effective, efficient or timely care when medicines and other supplies required for crucial elements of care become difficult or impossible to acquire. Many shortages seen during the COVID-19 crisis clearly affect safety, and they can exacerbate widespread problems with equity.

Just as critical incidents afford the opportunity to identify not just obvious active errors but also latent safety problems,[6] crises such as COVID-19 expose general supply chain weaknesses. In fact, product shortages often exhibit the combination of active and latent errors (or 'system problems') seen in investigations of critical safety incidents. Hurricane Maria in 2017, for example, converted a chronic shortage of sterile saline solutions (for intravenous administration) into an acute shortage when manufacturing capacity concentrated in Puerto Rico was damaged.[7] The current amplified risk of generic drug shortages follows from several decades of chronic shortage associated with fewer firms and concentrated sites of production.[8] These critical incidents are unlikely to abate, given the continued threat of future infectious disease outbreaks,[9] and the accelerating climate crisis, which will increase extreme weather, violent conflicts and other events that provoke acute shortages.[10]

The vulnerability of medical product supply—and its converse, resilience—has historically attracted little interest from clinicians, healthcare executives or those engaged in improving healthcare quality. Yet, as the COVID-19 pandemic has made obvious to even the casual observer, product shortages affect clinical practice, organisational performance and patient outcomes.

In this article, we outline what is known from the extensive literature on supply chain resilience and medical product shortage and use examples from both healthcare and non-healthcare

Table 1 Manufacturing problems as causes of supply chain disruptions

Risks to manufacture	Non-medical examples	Medical examples
Geographically concentrated manufacturing: Production concentrated in one or few locations, such that a localised disruptive event (natural or political) risks major disruption to product manufacturing[13]	▶ Earthquake and tsunami in Japan, and flooding in Thailand, disrupts automotive and electronics industries in 2011[35]	▶ Acute sterile saline shortage after hurricane damage to manufacturing plants, 2017[7] ▶ Risk of medical gloves shortage due to COVID-19 lockdown in Malaysia, the home of ~65% of the global supply[36]
Limited numbers of manufacturers: Few manufacturers, such that events affecting a single firm (eg, disruptions or decisions) risks major disruption to product manufacturing[17]	▶ Fire at Philip's semiconductor plant in 2000 disrupts Ericson's sole-source of chips for mobile phone production[37]	▶ Critical shortage of propofol (2009–2010) as two of three suppliers left US market[38] ▶ Shortages of nine childhood vaccines, 2000–2005, due to problems with the limited numbers of suppliers[39]
Scarcity of critical inputs: Resource inputs or parts whose scarcity risks major disruption due to non-substitutability of resources[14] or tightly-coupled production arrangements (just-in-time, short-cycle manufacturing)[17]	▶ Multiyear delays in production of Boeing Dreamliner due to shortage of aerospace fasteners[40]	▶ Disruptions in supply of raw or bulk materials responsible for drug shortages[33] ▶ Lack of meltblown, non-woven polypropylene for the production of surgical masks and N95 respirators[41]

industries to illustrate key vulnerabilities. As well, we offer examples of how these vulnerabilities have been exposed by the COVID-19 crisis. We consider some of the reactive adaptations forced on clinicians and administrators, most notably by PPE shortages, and identify several common failures of pandemic planning.

Because the vulnerability of medical product supply long pre-dates the pandemic, we also highlight the need for remedies that extend beyond pandemic response capacity—including from bold experimentation at the front line and by governments. Such reforms are contested and their prospects uncertain—no problem of this nature is amenable to easy solutions. Yet successfully addressing any quality problem begins with understanding its contributing factors. Thus, while we identify some promising reform directions, our main goal lies in outlining current knowledge about the factors contributing to supply chain disruptions and highlighting the need for broad and sustained engagement with the challenge of resilient medical product supply.

Understanding supply chain vulnerability for medical products

Quite a bit is known about what makes complex, contemporary global supply chains so vulnerable. Because no single, widely used framework for characterising supply chain vulnerabilities exists, particularly from the perspective of the supply user, we discuss examples in two broad categories—threats to product manufacture (table 1) and threats to local availability (table 2).

Manufacturing problems as risks to product supply chains

The consumers of medical—or other—products are often unaware of vulnerabilities in supply until shortages occur—when manufacture of the product has ceased or no longer occurs in sufficient quantities (table 1). Either event can occur when production is concentrated among few firms, which may elect to exit the market, or in few places, such that political or geophysical events disrupting local manufacture have global consequences.[11] For example, severe flooding in

Table 2 Transportation, regulation and supply chain management as threats to product availability

Risks to availability	Non-medical examples	Medical examples
Restrictions on the mobility of goods from the place of production to the place of consumption due to limitations on cross-border flows or transportation impedances[17]	▶ Oil tanker stuck in Suez Canal blocked ships carrying PlayStation II to consumers for 2004 Christmas season[42]	▶ Export bans, authorisations and related restrictions on critical supplies[19] ▶ Grounding of commercial flights challenge global freight movement[19]
Restrictions on quality and availability in specific markets due to regulatory compliance failures: Relevant to industries regulated for public or consumer safety, for example, medical products, aviation, automotive, telecommunication[18]	▶ Intentional contamination of milk with melamine identified in 2008, leading to health harms and food recalls[43]	▶ Heparin recall in 2008 after deaths and adverse events due to manufacturing plant adulteration[44] ▶ Multiple recalls of medicines containing valsartan in 2018 due to contamination risk[45]
Short-termism in sourcing activities: Sourcing activities that do not prioritise long-term supply reliability (eg, focus on upfront costs, sole sourcing, poor contract management)[8]	▶ Retail sourcing emphasis on large-scale producers lead to severe vegetable shortages in Europe, winter 2016–2017[46]	▶ Risks from single vendor contracts (eg, Sprint Fidelis defibrillator lead recall of 2007[47]) ▶ Poor contract management leading to drug shortages[48]

Thailand in 2011 puts factories producing 43% of the world's hard disk drives underwater, reducing production of personal computers for months and reducing global industrial output by 2.5%.[12]

The ability to manufacture products is also threatened by shortages of inputs, whether of raw resources or component parts. Input shortages may result from tightly coupled production arrangements, which limit inventory or increase complexity.[13] The severity of a shortage depends on the input's 'criticality', including its importance and the availability of potential substitutes or other mitigation strategies.[14]

Production vulnerabilities during the COVID-19 pandemic partly reflect drastically elevated demand, such as for PPE.[3] But production vulnerabilities can arise even with normal demand, especially when production is geographically concentrated, as with medical gloves and generic drug manufacture in India.[15] Moreover, the lean nature of the medical products industry is likely to challenge the capacity to produce sufficient quantities of any therapeutics that are shown to be effective in treating the disease.[16]

Other threats to local product availability

Even when manufacture occurs normally, multiple vulnerabilities can reduce availability of the right product in the right place (table 2). Lengthy transportation routes can prove fragile in times of need.[17] Additional challenges arise where companies fail to comply with the regulatory requirements that aim to reduce the risk of flawed products (eg, from the US Food and Drugs Administration or European Medicines Agency).[18] Conversely, inadequate regulatory arrangements can mean that available products are unsafe or product shortages are unexpected.[8]

Vulnerabilities affecting the availability of products during the COVID-19 pandemic have included movement limitations due to the reduction of international transportation capacity as well as the imposition of border controls and export restrictions, as countries prioritised the needs of their own citizens over those of international clients.[19] Further, those charged with sourcing products have been exposed as ill-prepared. Few had sourced supplies with a view to long-term resilience (eg, by favouring reusable products or domestic suppliers), managed PPE as a critical sector requiring vendor monitoring and risk management, or maintained supplies sufficient to avoid stockouts and shortages, including of goods such as generic drugs, for which demand has not been markedly elevated.[20 21]

Reactive and proactive solutions for medical product shortage

Shortages during the COVID-19 crisis have forced reactive adaptations. For clinicians, this has included shifts in normal standards of PPE use, such as extended use (eg, wearing the same PPE for encounters with different patients), reuse after sterilisation, alternative products (eg, positive pressure airflow helmets rather than N95 respirators) and even non-use.[22] The health and safety risks such reactive changes have created remain unclear. But shifts in policy on PPE use have challenged healthcare professionals' trust in system leaders and governments.[23] For healthcare administrators, product shortages make sourcing efforts much more complex. Many have had to deal with unknown and sometimes fraudulent suppliers or compete with other care delivery organisations for needed supplies, with concerning implications for care quality and equitable access.[24] Virtually all have faced increased costs as well as operational, legal or reputational risks.[25]

To an important extent, reactive efforts by clinicians and administrators have been made necessary by pandemic planning policy failures. Many health systems had not built or adequately sustained national or regional stockpiles. Many agencies tasked with coordinating national or regional joint procurement efforts lacked capacity. Much of the information infrastructure needed to fairly allocate supplies to users across countries or regions has proven insufficient.[26 27]And the pandemic has again exposed the weakness of market access regulation with respect to manufacturers' obligations to notify about, or provide assurances of, reliable and quality supply.[28]

Yet while necessary, more effective pandemic planning will not be a sufficient response. The underlying causes of supply chain vulnerability are not specific to the pandemic. They include the economic and regulatory arbitrage that lead brand name manufacturers to restrict generic competition, generic manufacturers to discontinue (or underinvest in) less profitable product lines, product supply chains to metastasise into complex networks of global manufacture and transport, and healthcare buyers to undervalue resilient supply.

Importantly, the pandemic has increased experimentation with proactive solutions, some of which take aim at these systemic challenges. The most promising, in our view, include increased interest in medical products that can be reused or repurposed, alongside the free and open-source hardware principles that support distributed and locally responsive refurbishment and manufacturing. Such experimentation has been most notable for PPE, often driven by front-line clinicians.[29] For more complex medical products, such as therapeutics or vaccines, governments and international agencies have experimented with ways to ensure adequate manufacturing capacity. This includes coordinated global strategies, such as advance market commitments for novel vaccines,[30] and the turn to enhanced domestic manufacturing and reduced dependence on limited suppliers of critical inputs for pharmaceuticals.[31] Less prominent but not absent have been challenges to the intellectual property rights that protect companies' monopoly control and high prices, through efforts to create global technology access pools and national

threats of compulsory licensing.[16 30] Such moves are not uncontested, nor is their effectiveness assured.[32] Yet they represent an important expansion of opportunity for reform—an opportunity whose potential will rest, in part, on the collective engagement of the healthcare community

CONCLUSION

Many of the policy and system issues that bear on medical product supply are not traditional areas of concern for the healthcare quality community. Quality improvement teams may take aim at medication administration errors due to poor labelling but not the shortage-induced use of unfamiliar products that contribute to such errors. They may target delays in care due to poor scheduling but not delays that arise when needed products are simply not available.

Quality improvement teams may not lack interest, but they will often lack leverage. Individual clinicians and care organisations can anticipate shortages and mitigate their harms once they arise (eg, the American Society of Health-System Pharmacists' Guidelines on Managing Drug Product Shortages),[33] but their capacity to prevent such shortages is inherently limited. Resilient sourcing strategies offer some remedies—sourcing from multiple vendors, securing local supply and maintaining inventory. But demand side strategies can only do so much. As with the persistent neglect of human factor issues in medical device design, many solutions necessitate 'controlling the supply side' at macroscale.[34] The pandemic may have made some of these controls more possible, but there are few easy solutions to systemic patient safety challenges. As with addressing any quality problem, the first step consists of recognising and understanding the contributing factors and system issues. The next lies with assuming a shared responsibility in developing effective solutions.

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