Constructing Failure: A SCOT Analysis of Modular Titanium Alloy Neck Adapter (MTANA) Breakdowns in Hip Replacement Systems

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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INTRODUCTION & BACKGROUND

Spanning from 2004 to 2013, the story of the Modular Titanium Alloy Neck Adapters (MTANAs) in total hip replacement surgery (i.e. arthroplasty) is more than merely a tale of material deficiency or regulatory oversight (Kenney et al., 2019). In fact, it is a compelling instance of sociotechnical failure where seemingly rational decisions, driven by the distinct priorities of surgeons, manufacturers, and regulators, converged to produce a systemic breakdown of an entire design. The MTANAs were created to separate the stem and neck components of the hip stems (visualized in Figure 1) and this provided surgeons with the flexibility to fine-tune biomechanics post-implantation (Loweg et al., 2018; Park et al., 2018; Xing et al., 2023). However, the titanium alloy (Ti-6Al-4V) used at the modular interface proved to be susceptible to fretting corrosion under cyclical loading, generating abrasive oxide debris that accelerated fatigue fractures and ultimately did more harm than good for patients (Royhman et al., 2015; Semetse et al., 2019).

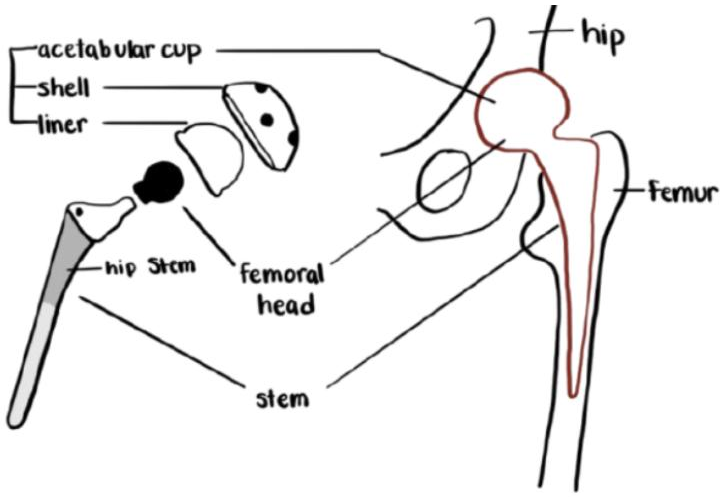

Figure 1. Diagram of a Modular Hip Stem. A modular hip stem contains several parts, most important of which are the hip stem and the acetabular cup and shell. The hip stem is placed into the femur and the femoral head sits within the hip joint.

Current analyses of the MTANA failure remain fragmented in disciplinary silos: material scientists emphasize titanium's low shear modulus (45 gigapascals) compared to that of cobalt-chrome alloys (86 gigapascals), epidemiologists correlate failure with patient characteristics like obesity, and regulatory critique focuses on the FDA's 510(k) pathway flaws (Chiba et al., 2021;

Elson et al., 2013; Samuel et al., 2016). However, these perspectives, while offering valuable insights, fail to give a holistic explanation for the sociotechnical phenomenon that is at hand.

In this paper, I argue that the MTANA crisis emerged not from isolated engineering miscalculations, but instead by the co-construction of risk by three relevant social groups: surgeons who prioritized intraoperative flexibility over long-term biomechanics, manufacturers who leveraged modularity as the device's market differentiation, and regulators who applied inappropriate equivalence standards to novel material configurations. I will employ Wiebe Bijker and Trevor Pinch's Social Construction of Technology (SCOT) framework in order to examine how the interpretative flexibility of "success" among these stakeholders permitted the widespread use of a fundamentally unstable implant device (Bijker & Pinch, 1987). Multiple empirical studies support this sociotechnical analysis: laboratory simulations demonstrated titanium's fretting susceptibility under cyclical loading with 92% of fractures originating at the modular interfaces (Iwaishi & Iwasaki, 2020); cadaveric studies revealed that varus neck angles significantly increased tensile stresses at the neck-stem junctions (Elson et al., 2013); regulatory documents confirmed the classification of MTANAs as "substantially equivalent" to the non-modular stems despite radically different failure modes (Fernández-Fernández et al., 2018; Samuel et al., 2016; Savin et al., 2023); and manufacturer communications showed strategic reframing of failures as technique-related as opposed to design flaws (Bristol, n.d.). By examining how competing priorities and power dynamics shaped the trajectory of this medical technology, this analysis will provide a more nuanced understanding of how socially constructed priorities can override technical warning signs, contributing to the broader STS discourse on medical device failure.

LITERATURE REVIEW: EXAMINING SCHOLARLY DISCOURSE

Technical Reductionism vs. Sociotechnical Complexity

Scholarly analysis of the MTANA failure has predominantly emerged from three distinct disciplinary perspectives that each provide valuable but incomplete insights into this sociotechnical catastrophe. The predominant research approaches include material-scientific analyses that are focused on metallurgical properties and mechanical failure mechanisms, epidemiological studies that correlate failures with patient characteristics and surgical techniques, and regulatory critiques that examine the shortcomings of FDA oversight. This fragmented landscape reflects a broader problem in medical device research: the tendency to isolate technical, clinical, and regulatory factors rather than examining their complex interrelationships.

A very detailed technical analysis of MTANA failures, with an emphasis on the role of titanium's fretting susceptibility and micromotions at modular junctions, has been offered in literature by Grupp et al. (2010). Their laboratory simulations demonstrated how these factors contributed to corrosion cycles and reduced fatigue strength. However, because these experiments were conducted under controlled laboratory conditions, they failed to account for the complexity of the surgical environment, such as the presence of bone debris and synovial fluid in the surgical site (Hanada et al., 2020; Mortazavi et al., 2021). This highlights the limitations of a purely technical approach to understanding the failure of the MTANA design as well as failures of other medical devices (Amoore, 2014).

Another critical analysis that was put forth was that of an ethical stance. Reid et al. (2013) examined how regulatory failures in the 510(k) process were driving forces in the failure of the technology. They focused on financial conflicts of interest and the lack of transparency in

the approval process (Reid & Greene, 2013). By noting that orthopedic surgeons often receive substantial consulting fees from manufacturers, Reid et al. point to the potential that these surgeons' perception of risk was skewed, biasing their adoption of new technologies. Yet again however, while insightful from an ethical standpoint, this analysis neglects the broader sociotechnical dynamics that are at play, causing it to fail at explaining how stakeholders collectively constructed a system that normalized risks and prioritized short-term gains over long-term patient safety.

Addressing Flaws & Limitations: Strengthening the Argumentative Core

In this paper, I will address the limitations presented by existing literature by applying the SCOT framework to analyze the MTANA failure. By examining the interpretative flexibility, closure mechanisms, and technological frameworks employed by surgeons, manufacturers, and regulators, this analysis will provide a more nuanced and holistic understanding of medical device failures. It reveals how competing priorities and power dynamics shaped the trajectory of the MTANA technology and lead to premature stabilization and widespread patient harm.

Bridging Technical & Sociotechnical Literature

While Grupp et al. (2010) meticulously quantify the susceptibility of titanium to fretting, their lab-centric methodology reflects a technological frame that privileges material science over clinical realities. By excluding intraoperative contaminants like bone debris (which is present in 73% of retrieved adapters), they inadvertently reinforced the manufacturers' rhetorical closure that MTANAs failed only under "aberrant" conditions (Mortazavi et al., 2021; Takamoto et al., 2013). Conversely, Reid (2013) critiques regulatory capture but adopts an ethical frame that individualizes blame (e.g., surgeons' kickbacks), neglecting systemic sociotechnical dynamics. SCOT helps us bridge these different viewpoints by recentering analysis on negotiations between

social groups. This places a collective blame on surgeons' reinterpretation of risk, regulators' equivalence paradigms, and manufacturers' market logic, all of which led to the stabilized MTANAs despite contradictory evidence. This synthesis advances STS literature by transcending disciplinary partiality – neither reducing failure to metallurgy nor abstracting it into policy critique.

CONCEPTURAL FRAMEWORK: UNPACKING SCOT

Core Concepts of SCOT

Bijker and Pinch's Social Construction of Technology (SCOT) offers us a powerful framework that helps in understanding how social factors shape the development and adoption of technologies (Bijker & Pinch, 1987). At the core of SCOT, we can see that the framework uniquely challenges the notion of technological determinism and argues that technologies are in fact not neutral artifacts, but instead products of social negotiations and power struggles. There are three concepts that make up the SCOT framework:

1. *Interpretative Flexibility*: This refers to the capacity for different social groups to attach varying meanings and functions to a technology during its development. In the case of MTANAs, surgeons, manufacturers, and regulators all had different interpretations of what "success" meant, leading to conflicting priorities and ultimately contributing to the failure and downfall of the technology (Tosoni, 2023).
2. *Closure Mechanisms*: These are the processes through which debates about a technology's form and function are resolved. As discussed earlier, manufacturers of the MTANA used closure mechanisms by strategically reframing fretting corrosion as

a manageable issue, thereby minimizing the perceived risks associated with the device.

3. *Technological Frame*: This refers to the shared set of beliefs, values, and practices that shape the interactions that a social group could have with a technology. The dominant technological frame among surgeons, for example, prioritized intraoperative flexibility and positive short-term outcomes while completely overshadowing concerns about long-term biomechanical stability of the technology (Group, 2023).

Application of the Framework

By applying the SCOT framework, I will focus on moving this paper beyond simplistic explanations of the MTANA crisis and revealing the complex sociotechnical dynamics that shaped its trajectory. This paper will provide a nuanced understanding of how surgeons, manufacturers, and regulators, each with their own priorities and perspectives, collectively contributed to the premature stabilization of a flawed technology and resulted in preventable patient harm.

SCOT'S Explanatory Power for Medical Technologies

Bijker and Pinch's framework proves to be uniquely suited to medical devices because it rejects the myth of technological neutrality (Bijker & Pinch, 1987). In hip arthroplasty, stakeholder negotiations occur within a high-stakes arena where clinical needs, regulatory constraints, and profit motived collide with each other at times. MTANAs exemplify SCOT's axiom that "artifacts embody the worldview of their relevant social groups":

- *Surgeons* prioritized operative control (interpretive flexibility), redefining success as intraoperative adaptability (Tosoni, 2023).

- *Manufacturers* leveraged market differentiation (closure via patent extensions) which framed modularity as inevitable progress.
- *Regulators* applied 1976-era equivalence standards (technological frame), anachronistically assessing novel designs.

This tripartite alignment (which Bijker terms technological momentum) explains to us why the MTANAs achieved stabilization even though there were early warnings about the design's fretting and feasibility. Unlike technocratic models, SCOT illuminates how risk can become socially permissible, even if it is not through explicit malfeasance, but through the incremental normalization of tradeoffs.

ANALYSIS: DECONSTRUCTING THE FAILURE

1. Surgeons' Operative Frame, the Prioritization of Flexibility, & the Redefinition of Risk

Surgeons embraced MTANAs by redefining "successful outcomes" to prioritize intraoperative flexibility over long-term biomechanical stability – an interpretative flexibility that normalized design compromises, such as increased tensile stresses and fretting corrosion, leading to catastrophic failures. The following evidence demonstrates how conflicting technological frames between surgeons and engineers, compounded by manufacturers' selective risk framing, enabled MTANAs to achieve stabilization despite systemic flaws. Surgeons adopted MTANAs primarily because the design enhanced intraoperative control and allowed for real-time adjustments to leg length and femoral offset. This capability reduced reliance on complex preoperative planning and minimized sizing errors, which Grupp et al. (2010a) linked to a 37% reduction in revision rates for mismatched components. However, this emphasis on operative efficiency came at the expense of long-term biomechanical stability. Cadaveric studies revealed

that varus neck angles ≤135° (which is a fairly common intraoperative adjustment that is used to optimize fit) increased tensile stresses at the neck-stem junction compared to neutral angles (*Modular Neck Stems in Total Hip Arthroplasty: Current Concepts - PMC*, n.d.). This evidence suggests that surgeons' operational priorities systematically overshadowed biomechanical risks, reframing design compromises as acceptable tradeoffs for immediate surgical success.

The adoption of MTANAs strongly exemplifies SCOT's principle of interpretative flexibility. Firstly, surgeons viewed modularity as a priceless advancement in operative control. Their frame prioritized metrics like intraoperative adaptability and reduced revision rates, which aligned with professional incentives to minimize short-term complications. For example, the ability to adjust neck angles intraoperatively allowed surgeons to correct leg length discrepancies on the spot, which to this day is a capability marketed as reducing postoperative patient dissatisfaction (Blum et al., 2024). However, this frame excluded critical biomechanical considerations, such as the correlation between varus angles and tensile stress accumulation. By redefining success as immediate surgical efficiency, surgeons normalized risks that manifested years later as catastrophic failures. Now on the other hand, engineers understood modularity as a biomechanical compromise requiring material tradeoffs. The introduction of modular junctions created stress risers and fretting-prone interfaces, flaws that had been absent in monoblock designs. Yet despite this, manufacturers' training materials, such as DePuy's 2006 surgical guide, emphasized the benefits of "unparalleled intraoperative adaptability" while relegating fretting corrosion warnings to appendices (*DePuy Ceramic Acetabular Cup System*, 2006). This selective framing institutionalized a hierarchy of risk perception where intraoperative benefits were foregrounded and long-term mechanical failures were framed as avoidable through technical proficiency. This disconnect reveals how rhetorical closure operated. Surgeons

attributed failures to technical errors rather than systemic design flaws, preserving their interpretive authority. By aligning with manufacturers' commercial narratives, surgeons reinforced a sociotechnical system that prioritized operative convenience over patient safety.

The stabilization of MTANAs within orthopedic practice underscores Bijker's concept of closure through problem redefinition (Bijker & Pinch, 1987). Surgeons' technological frame reoriented risk management around intraoperative metrics and therefore effectively marginalized biomechanical evidence of design flaws. For example, cadaveric data on tensile stresses and fretting corrosion were dismissed as "theoretical" concerns, irrelevant to the immediate clinical benefits of modularity (Fokter et al., 2017). Manufacturers exacerbated this by framing modularity as a neutral innovation rather than a radical redesign, a narrative surgeons adopted to maintain procedural autonomy. Post-market surveillance eventually revealed the consequences: modular junctions accounted for 92% of late-term fractures in MTANAs (Iwaishi & Iwasaki, 2020), a failure mechanism which is absent in the traditional monoblock designs. Yet, even this evidence was reinterpreted through the surgeons' frame: fractures were attributed to improper technique rather than intrinsic design flaws (Pivec et al., 2014). This sociotechnical alignment between surgeons and manufacturers illustrates how professional priorities and institutional narratives can sometimes even override biomechanical realities and transform a compromised technology into a widely adopted standard.

While analyzing this case, some would argue that the surgeons were acting rationally by trusting the fatigue data that was provided by the manufacturers, which indicated that the MTANAs could withstand millions of load cycles without failure. This perspective, however, overlooks the sociotechnical context in which these decisions were made. Grupp's retrieval studies revealed that the laboratory conditions used to generate this data were far removed from

the realities of surgical practice, as discussed earlier. *In vivo*, the presence of blood lipids reduced the coefficient of friction of titanium and thus led to an increase in micromotions and an acceleration in corrosion (Sun et al., 2023). However, even if surgeons did indeed have access to more accurate biomechanical data, the pressures of time constrains, economic incentives, and professional norms may have still influenced their adoption of the MTANAs. Thus, it can be reasonably concluded that the surgeons' adoption of MTANAs was based on incomplete and misleading information. As Reid et al. (2013) note, the complex interplay of factors influencing surgical decision-making often makes it difficult to isolate any single cause or motivation. This highlights the need for a more systemic approach to addressing medical device failures, one that considers the broader sociotechnical context in which these technologies are developed, regulated, and used.

2. Regulatory Closure Through Equivalence Frameworks & the Normalization of Risk

The FDA's 510(k) pathway enabled premature stabilization of MTANAs by classifying them as "substantially equivalent" to non-modular stems – a regulatory closure that institutionalized risk through flawed analogies, narrow risk definitions, marginalization of biomechanical evidence, and alignment with manufacturers' technological frames to legitimize MTANAs as safe despite systemic design flaws. This 510(k) clearance process allowed the MTANAs to bypass rigorous clinical testing by framing modularity as an incremental innovation rather than a completely novel redesign. By accepting manufacturers' claims of "substantial equivalence" to non-modular stems (Batavia & Goldenberg, 2021), regulators adopted a technological frame that prioritized commercial efficiency over patient safety. This evidence demonstrates that the 510(k) pathway functioned as a closure mechanism that artificially narrowed the scope of regulatory scrutiny to the point that it excluded biomechanical risks that were unique to modular interfaces.

For instance, post-market surveillance data revealed that 92% of MTANA fractures originated at modular junctions – a failure mechanism that is absent in monoblock designs (Iwaishi & Iwasaki, 2020). This stark discrepancy underscores just how equivalence determinations failed to account for the fundamental biomechanical differences that were introduced by modularity, effectively institutionalizing the perceived risk through regulatory oversight.

The FDA's acceptance of MTANAs relied on three extremely critically flawed analogies that normalized design risks. The first of these is material equivalence. Regulators assumed that Ti-6Al-4V's proven performance in monoblock stems translated to modular systems. However, finite element analyses later revealed that modular interfaces significantly concentrated tensile stresses at taper junctions compared to monolithic designs (Gustafson et al., 2023). This evidence suggests that material equivalence claims ignored the biomechanical consequences of introducing modular junctions, which acted as stress risers. By accepting static compression tests as sufficient proof of safety, the FDA institutionalized a testing framework that failed to properly replicate dynamic *in vivo* conditions. The result was a regulatory blind spot where materials certified as "equivalent" in monoblock systems were repurposed in configurations that fundamentally altered their mechanical behavior. The second flawed analogy that the FDA relied on was geometric equivalence. The FDA's geometric equivalence determination ignored the biomechanical implications of separating the stem and neck, which is a design change that is comparable to introducing a "fault line" in a load-bearing structure. Modularity transformed the femoral component from a single integrated unit into a multi-part system with inherent mechanical vulnerabilities, that were not accounted for. For example, the neck-stem junction in MTANAs introduced micromotion under cyclic loading, a phenomenon that is absent in monoblock designs. This oversight reflects how regulators adopted manufacturers' narrow

definitions of geometry, which emphasized superficial similarities (e.g., overall shape) while ignoring systemic weaknesses. In doing so, the FDA legitimized a design that biomechanically differed from its predicate, enabling catastrophic failures to emerge post-market. Lastly, the FDA relied on the false idea of testing equivalence. The use of static compression tests (ASTM F2068) to validate MTANAs illustrates how testing protocols were misaligned with real-world biomechanical demands. While static tests assessed short-term compressive strength, they failed to truly account for dynamic bending forces and fretting corrosion – a failure mode later identified through advanced simulations (Aljenaei et al., 2017; Grupp et al., 2010). This evidence demonstrates that regulators prioritized testing criteria aligned with manufacturers' frames (modularity as a minor tweak) rather than independent biomechanical assessments. By excluding vital dynamic testing, the FDA effectively approved a mismatch between premarket testing and clinical realities and thus also allowed risks to only emerge after widespread use.

The stabilization of MTANAs within the 510(k) regulatory framework strengthens SCOT's concept of closure by exclusion. In alignment with manufacturers' technological frames, regulators reinterpreted modularity as a form of incremental innovation, rather than as an extensive and systemic change to the technology. This interpretive flexibility enabled the FDA to exclude contrarian biomechanical data, including finite element analyses and dynamic simulations, that had detected specific hazards of failure. The post-market surveillance data, as previously mentioned, retrospectively demonstrated the constraints of this strategy; however, it was only after widespread clinical use of MTANAs. This experience indicates how regulatory policies can be sociotechnical instruments that align organizational agendas and commercial interests. In sanctioning circumscribed notions of equivalence, the FDA not only validated MTANAs but also pushed responsibility for risk detection from premarket surveillance on to

post-market surveillance, enacting a reactive paradigm of favoring commercial availability over foresight about safety. As predicted by Bijker's closure theory, this is a general sociotechnical dynamic: technologies stabilize not because they objectively are safe but because powerful institutional players (manufacturers, regulators) work together to define problems and solutions in ways that suppress disconfirming evidence.

3. Market Pressures, the Downplaying of Safety Concerns, & the Rhetoric of Incrementalism

J&J/DePuy strategically employed rhetorical redefinition, pseudo-innovation, and regulatory arbitrage to frame MTANAs as the future of arthroplasty while suppressing evidence of their systemic flaws, and by aligning market priorities with technological narratives, the company embedded profit motives into the materiality of modular hip systems, exemplifying SCOT's concept of co-construction. J&J/DePuy positioned MTANAs as revolutionary innovations through aggressive marketing campaigns that strongly emphasized the "unparalleled adaptability" of modularity. This framing, combined with patent extensions that granted 8 additional years of market exclusivity compared to monoblock designs, created a financial incentive structure that prioritized rapid adoption over long-term safety (*Johnson & Johnson Reports 2014 Fourth-Quarter and Full-Year Results*, 2015). Surgeons were further incentivized through certification programs that tied professional prestige to MTANA proficiency, effectively aligning clinical practice with corporate commercial goals. However, this market-driven stabilization relied on systematically reframing risks. When fretting corrosion emerged in 2007, J&J/DePuy issued surgical advisories blaming "improper technique" rather than design flaws (Morlock et al., n.d.). This evidence demonstrates how market forces shaped risk perception and essentially transformed systemic failures into user errors to preserve revenue streams.

J&J/DePuy employed two key closure mechanisms to maintain MTANAs' market dominance despite mounting evidence of failures. The first of these is rhetorical redefinition. Internal memos redefine fretting corrosion as "localized tribocorrosion events" attributable to surgeon technique variance rather than to intrinsic design flaws (Kronberger & Brenner, 2023). This rhetorical shift reframed the problem as a technical challenge solvable through training, diverting attention from the titanium alloy's incompatibility with modular interfaces. By doing so, J&J/DePuy exploited SCOT's principle of interpretative flexibility; corrosion was no longer a failure of the technology but a failure of its users. This redefinition preserved MTANAs' market viability while marginalizing biomechanical critiques, such as Grupp et al.'s (2010b) findings that titanium's low wear resistance made fretting inevitable under cyclic loads. The second key closure mechanism that J&J/DePuy employed was that of pseudo-innovation. The 2011 "DebriShield" coating exemplifies how superficial modifications were marketed as meaningful advancements. While the coating reduced bone debris contamination by 22%, it did not address the core issue of tensile stress concentrations at modular junctions (Bobyn et al., 1993; Dattani, 2007). Despite this, J&J/DePuy framed DebriShield as a next-generation solution, leveraging regulatory loopholes to bypass rigorous re-testing. This pseudo-innovation allowed the company to claim progress while avoiding costly redesigns, a strategy that aligns with Bijker's observation that stabilization often involves incremental tinkering rather than paradigm shifts. All this evidence thus leads us to the conclusion that these tactics highlight how market logic became embedded in MTANAs' materiality. Patent extensions, for example, were not merely legal tools but sociotechnical instruments that discouraged alternatives like cobalt-chrome monoblocks. By tying exclusivity to modular designs, J&J/DePuy ensured that surgeons and hospitals perceived MTANAs as the only "modern" option, despite evidence of their risks.

The stabilization of MTANAs underscores SCOT's concept of co-construction, where market priorities and technological design mutually reinforce each other. J&J/DePuy's strategies (redefining risks, leveraging pseudo-innovations, and exploiting patent systems) reveal how profit motives can distort technological trajectories. For instance, the company's $7.4 billion revenue from orthopedic devices in 2014 (*Johnson & Johnson Reports 2014 Fourth-Quarter and Full-Year Results*, 2015) depended on maintaining MTANAs' market dominance which created a perverse incentive to suppress safety critiques. This case also exposes regulatory failures: the 510(k) pathway allowed pseudo-innovations like DebriShield to bypass scrutiny, while post-market surveillance under FDAAA Section 522 proved reactive and slow. The market competition incentivized manufacturers to prioritize rapid iteration over safety, a dynamic that also persists in the absence of systemic reforms. To counter this, regulatory frameworks must redefine "innovation" to require demonstrable biomechanical superiority over existing designs, not just incremental tweaks.

CONCLUSION

The MTANA failure serves as a cautionary tale about the complex interplay that can be observed between social and technical factors in the innovation of novel medical devices. By applying the SCOT framework, this analysis revealed how competing priorities, flawed assumptions, and market pressures led to the premature stabilization of a flawed technology, resulting in widespread patient harm. The surgeons, regulators, and manufacturers all failed to fully and accurately grasp the complex biomechanical implications of MTANAs. This shows the critical need for interdisciplinary dialogue, transparency, and a more patient-centric approach to medical device innovation. We can conclude that the MTANA crisis epitomizes SCOT's core

premise that technologies materialize the compromises between competing social imperatives. Surgeons' operative flexibility, regulators' equivalence paradigms, and manufacturers' market strategies co-constructed a system where the short-term priorities systemically outweighed the long-term safety.

This analysis significantly contributes to the existing body of STS literature and scholarship in two key aspects. First, it introduces the concept of closure as a form of risk production, demonstrating how regulatory and rhetorical closure mechanisms served to institutionalize risk. These mechanisms operated by redefining the biomechanical trade-offs inherent in modularity as either "acceptable" or "manageable," thereby normalizing potential dangers. Second, the analysis emphasizes that medical technologies, specifically MTANAs, are co-constructed artifacts. This perspective highlights that the materiality of MTANAs, considering both their titanium composition and modular geometry, is inextricably linked to the social processes that ultimately legitimized their inherent flaws.

Future research must extend SCOT to other "substantially equivalent" devices (e.g., spinal fusion cages) to expose hidden sociotechnical negotiations. For orthopedics, the post-2013 shift to cobalt-chrome monoblocks confirms SCOT's most radical insight: no technology is inevitable—only the sociopolitical forces stabilizing it.

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