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Review Article

Pharmacological Considerations in Vaccination: Age-Specific Strategies for Pediatric and Geriatric Populations

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A B S T R A C T

Vaccination remains one of the most effective public health strategies for preventing infectious diseases across the lifespan. However, age-specific immunological differences demand tailored pharmacological approaches in pediatric and geriatric populations. In children, immune immaturity, maternal antibody interference, and safety considerations necessitate fractional dosing, carefully timed booster schedules, and minimally reactogenic adjuvants. Combination vaccines and novel delivery systems, including microneedle patches and intranasal formulations, have further optimized pediatric immunization by reducing injection burden and improving acceptability. In contrast, older adults face immunosenescence, inflammaging, and the added burden of comorbidities, which collectively reduce vaccine responsiveness and durability. Pharmacological strategies in geriatrics emphasize dose intensification, potent adjuvants (MF59, AS01, Matrix-M), and next-generation platforms such as recombinant protein subunits and mRNA-based formulations. High-dose influenza vaccines, adjuvanted shingles vaccines, and recently licensed RSV and pneumococcal conjugate vaccines illustrate this paradigm. Age-related pharmacokinetic and pharmacodynamic differences also underscore the need for individualized approaches, as clearance, biodistribution, and immune priming vary significantly between neonates and older adults. Safety remains paramount, with febrile seizures in children and multimorbidity-linked adverse events in older adults requiring vigilant monitoring. Emerging innovations, including systems vaccinology, nanoparticle platforms, and thermostable vaccines, promise a future of personalized and lifelong immunization strategies. This review highlights the pharmacological basis for pediatric versus geriatric vaccine design, emphasizing that one-size-fits-all approaches are inadequate. Instead, age-tailored vaccine strategies informed by immune profiling, pharmacological principles, and regulatory frameworks are essential for optimizing protection across the lifespan.

Keywords: Vaccination; Pediatrics; Geriatrics; Immunosenescence; Adjuvants; Pharmacology; Immunization strategy; Pharmacokinetics; Vaccine safety; Precision vaccinology

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INTRODUCTIOPN

Vaccination has always been one of the most powerful tools in protecting health across a person's lifetime. But children and older adults stand at very different points on the immune spectrum, which means their vaccines must be designed and delivered in very different ways. In children, the immune system is still learning and developing, and protection from maternal antibodies while helpful can sometimes interfere with how well vaccines "take." That is why pediatric vaccines are usually given in carefully timed doses, often with multiple boosters, and why adjuvants are used very sparingly to avoid overstimulating the young immune system [1,2]. In contrast, older adults face the opposite problem: the immune system slows down with age, a process called immunosenescence. This means vaccines often need stronger formulations, higher doses, or powerful adjuvants to help generate a protective response [3,4]. Looking at vaccination through this pharmacological lens—dose, formulation, adjuvant choice, and delivery system helps us understand why "one size fits all" simply doesn't work [5].

For infants, maternal IgG passed through the placenta provides important early protection, but it can also blunt how

vaccines like measles work. Studies have shown that giving measles vaccine too early can protect temporarily but the effect fades quickly, reinforcing the need for boosters later in childhood [6–8]. Global guidelines, such as those from WHO and CDC, build these realities into their schedules, spacing primary doses and boosters across childhood and adolescence [9,10]. Combination vaccines, such as the six-in-one DTaP-IPV-HepB-Hib, have been a game changer, reducing the number of injections without compromising protection and making life easier for both parents and healthcare workers [11].

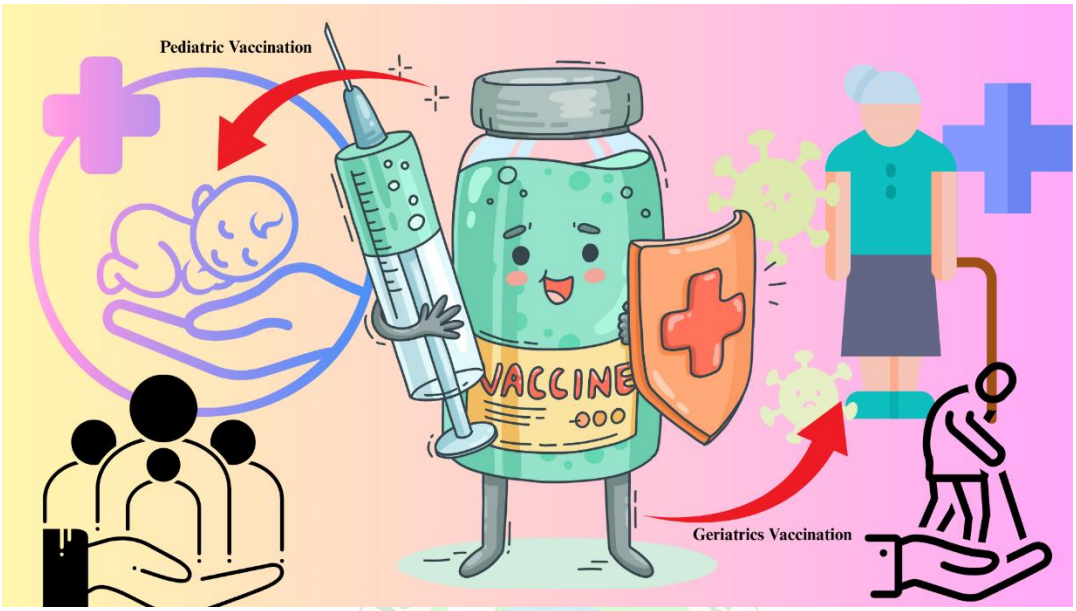

Figure 1: From Infancy to Old Age: Optimizing Vaccination for Every Stage of Life

Older adults, however, face a different set of challenges. Aging affects both the innate and adaptive arms of the immune system—dendritic cells lose some of their ability to activate T cells, B-cell diversity narrows, and chronic low-grade inflammation ("inflammaging") can blunt vaccine responses [12]. To overcome this, high-dose influenza vaccines and those with adjuvants like MF59 have shown much stronger protection than standard formulations [13,14]. Newly licensed vaccines against RSV also show strong benefits in adults over 60, reducing the risk of serious lower respiratory tract illness [15]. Pneumococcal vaccines have also been updated: newer conjugate formulations (PCV20, PCV21) mean that many older adults now need only a single dose for broad protection [17]. Innovation is not limited to older adults. For children, researchers are testing new delivery methods such as microneedle patches, intranasal sprays, and needle-sparing devices—all designed to make vaccines less painful, more acceptable, and easier to deliver in low-resource settings [15]. Safety remains a critical focus in both groups. For instance, while rare cases of myocarditis have been linked to mRNA vaccines in adolescent males, the overall benefits far outweigh the risks [16]. For older adults, studies confirm that enhanced influenza vaccines remain just as safe as standard-dose options [17].

Geriatrics — Immunosenescence, Inflammaging, and Comorbidity Effects

As people grow older, their immune system does not simply "weaken"—it **changes in character**. This process, called *immunosenescence*, involves a gradual shrinking of the thymus, reduced output of fresh naïve T cells, and a build-up of exhausted memory cells that can no longer respond effectively. Antigen-presenting cells, which act as the sentinels of the immune system, also show slower activity. Together, these shifts mean that older adults take longer to mount a response to vaccines, and the protection they gain tends to fade faster [18].

Layered on top of this is **inflammaging**—a chronic, low-grade inflammatory state that acts like background "static" in the immune system. Instead of being quiet until needed, the system is already humming with inflammatory signals, leaving little reserve for strong, targeted responses when vaccines or infections appear [19]. Metabolic changes, such as less efficient mitochondria and impaired energy balance, further drain the immune system's capacity. Encouragingly, new research suggests that **metabolic interventions and advanced adjuvants** may help restore some of this lost potential [20]. Another subtle but important shift happens in the **B-cell compartment**. With age, the diversity of B-cell receptors narrows, meaning the body has fewer "options" to recognize and fight new pathogens. A recent *Cell Reports* study in 2023 confirmed this loss of diversity in both animal models and humans, emphasizing that it directly limits antibody quality after vaccination [21]. It is not just biology that matters, but also the **burden of chronic diseases and medications**. Many older adults live with diabetes, heart disease, cancer, or lung problems, all of which chip away at vaccine effectiveness. A systematic review in *Lancet Healthy Longevity* (2023) found that these comorbidities significantly reduced antibody responses to COVID-19 vaccines in older adults [22], while another pooled analysis showed similar issues with influenza vaccines [23]. These challenges have sparked the field of **geriatric vaccinology**, which takes a

very different approach compared to pediatrics. Instead of prioritizing "gentle" stimulation, elderly vaccines often require **dose intensification or potent adjuvants**. Examples include the MF59-adjuvanted influenza vaccine, the AS01-adjuvanted shingles vaccine, and high-dose influenza vaccines. Meta-analyses from 2022–2024 consistently show that these approaches boost both antibody levels and real-world protection in older populations [24,25]. In sharp contrast, **pediatric vaccinology** has the opposite goal: avoiding overstimulation of an immature immune system. Infants and young children typically receive vaccines formulated with minimal adjuvants—most often aluminiumsalts—or use innovative strategies like **fractional dosing, intradermal delivery, microneedle patches, or lipid nanoparticles at lower mRNA doses**. These strategies strike a balance between **priming a strong immune memory** and **keeping side effects low**, ensuring that children are protected while parents and caregivers feel reassured [26,27].

Table 1: Pharmacological profiling methods and their potential applications in pediatric and geriatric vaccination.

Profiling Method	Key Insights	Potential Applications
Biophysical profiling (BLIPI)	Detects immune activation (e.g., sepsis) using minimal blood	**Point-of-care monitoring** to inform vaccination timing in preterm infants
Multi-omics (mucosal + blood)	Reveals durable and mucosal-skewed immunity after infection	Design of **mucosal or intranasal vaccines** that better match infant immune responses
Transcriptomic and cellular profiling	Baseline ISG signature and cell composition predict antibody titers	Development of **predictive biomarkers** to optimize booster timing or adjuvant use

PHARMACOLOGICAL CONSIDERATIONS

Dosage and Formulation

Optimizing dose and formulation is a primary pharmacological strategy to maximize vaccine benefit in both children and older adults. In pediatrics, dose-sparing approaches and age-specific schedules are routinely used to accommodate immune immaturity, maternal-antibody interference, and supply or operational constraints. Fractional/intradermal administration of inactivated poliovirus vaccine (fIPV) has proved immunogenic in randomized and programmatic studies and is now incorporated into WHO guidance as a supply-stretching option during shortages and campaigns [28,29]. Similarly, randomized trials of fractional pneumococcal conjugate vaccine (PCV) schedules have shown that 20–40% doses given in a 2-plus-1 schedule can be non-inferior for many serotypes, supporting dose-sparing strategies in resource-limited settings [30,31]. Large programmatic evaluations and randomized studies from Bangladesh and other settings have also demonstrated the safety and acceptable immunogenicity of reduced-dose IPV and dose-sparing PCV regimens when used with appropriate scheduling and booster timing [32,33]. Combination (hexavalent and other multivalent) pediatric vaccines continue to offer important operational and adherence advantages without compromising immunogenicity, and recent reviews summarize their favorable safety and programmatic profiles [34].

For older adults the pharmacological response is the opposite: formulation intensification is the dominant approach to overcome immunosenescence. Multiple large randomized controlled trials and pragmatic registry studies show that high-dose influenza vaccines elicit higher antibody titers and are associated with reduced influenza-related hospitalizations and severe outcomes compared with standard-dose vaccines in adults ≥65 years [35,36]. Likewise, MF59-adjuvanted influenza vaccines produce improved immunogenicity and real-world effectiveness comparable to high-dose formulations in many analyses, and head-to-head observational studies suggest similar or superior effectiveness of adjuvanted vaccines in certain subgroups [37–39]. These findings have driven many national immunization programs to preferentially recommend high-dose or adjuvanted influenza formulations for older adults. Beyond influenza, recent advances in adult vaccine platforms include adjuvanted protein-subunit vaccines and combined mRNA formulations: large phase-3 programs of combination mRNA flu/COVID vaccines (e.g., Moderna mRNA-1083) and other next-generation products have reported superior antibody responses and acceptable safety in adults ≥50 years, offering a practical way to boost uptake and broaden protection in older cohorts [40–42]. Finally, updated pneumococcal policy (ACIP, 2024–2025) and the licensure of higher-valent PCVs for adults (PCV20/PCV21) simplify adult schedules—another formulation-driven, programmatic tactic to improve protection in aging populations [43,44].

In short, pediatric dose and formulation strategy emphasizes timing, fractional dosing where appropriate, booster scheduling, and combination products to achieve durable immunity with minimal reactogenicity, whereas geriatric strategies emphasize increased antigen content, potent adjuvants, platform innovation (adjuvanted protein, high-dose inactivated, or mRNA combos), and simplified adult formulations/policies to overcome immunosenescence and improve real-world effectiveness.

Safety and Tolerability

Vaccines are overwhelmingly safe, but safety concerns and tolerability differ between children and older adults — and acknowledging those differences frankly helps clinicians, caregivers, and patients make informed decisions with empathy and clarity.

Pediatrics. Young children can experience specific, mostly short-lived vaccine-related events that clinicians and parents notice and worry about. A small but well-documented increased risk of febrile seizures occurs after some childhood vaccines (notably measles-containing vaccines and the combined MMRV), typically 5–12 days after immunization; these events are usually self-limited and do not cause long-

term neurologic harm, and public-health guidance therefore still strongly supports timely vaccination because disease risks exceed this small risk [45–47]. Immediate hypersensitivity and anaphylaxis after vaccination are rare in children: active surveillance and systematic reviews place anaphylaxis rates at well under a few cases per million doses for most routine vaccines, but rapid recognition and treatment (epinephrine) are essential when they occur [48,49]. Large recent pediatric series of suspected vaccine allergies (including COVID-19 vaccine programs) show that most children referred for possible allergy tolerate subsequent doses without severe reaction after appropriate evaluation, which is reassuring for caregivers and supports completion of schedules whenever safely possible [50].

Geriatrics. Older adults face a different safety landscape driven largely by multimorbidity and polypharmacy. Age-related physiological changes (renal/hepatic decline, altered body composition) plus the frequent use of multiple medications increase the baseline risk of adverse drug reactions (ADRs) and complicate attribution of symptoms to vaccines versus underlying disease or drug interactions [51,52]. Recent narrative and systematic reviews underline that multimorbid older individuals suffer higher rates of ADR-related hospitalization and that careful medication review is an important part of vaccination planning in geriatrics [51,53]. Large population studies that examined adverse events after COVID-19 and influenza vaccines in older cohorts found that most serious events are rare, but they also documented heterogeneity in risk by comorbidity strata and, in some analyses, small transient increases in specific events (for example, thrombotic or cerebrovascular signals in very large administrative datasets), emphasizing the importance of individualized risk–benefit counseling and active post-marketing surveillance [54].

In practice, this means clinicians should (a) review current medications and frailty/comorbidity status before vaccination, (b) counsel patients and families about expected, generally mild local/systemic reactions, and (c) ensure clear pathways for reporting and managing rare serious events — all while emphasizing that for most older adults the benefits of vaccination (reduced hospitalization, severe disease and death) substantially outweigh these risks [54].

Table 2: Key patents and regulatory documents relevant to pediatric and geriatric vaccination strategies.

Sr. No	Patent / Document (title)	Target group / Use	Short summary	Reference
1	US 8,778,275 B2 — Methods for producing vaccine adjuvants (microfluidized oil-in-water emulsions such as MF59)	Geriatric / adjuvant production	Methods for producing oil-in-water emulsions (e.g., MF59) at commercial scale with improved stability — relevant to adjuvanted vaccines for older adults.	[55]
2	EP 2 364 721 B1 — Vaccine compositions comprising a saponin adjuvant	Geriatric / adjuvant (QS-21 family)	Describes saponin-containing adjuvant compositions (AS01-like) to boost humoral/cellular immunity — applicable to adult/elderly vaccines.	[56]
3	US 2018/0177861 A1 — Methods of use of influenza vaccine (high-dose)	Geriatric (high-dose influenza)	Use and dosing of high-dose inactivated influenza vaccine (Fluzone® High-Dose; 60 µg HA/strain) to improve responses in ≥65 yrs.	[57]
4	US 10,729,757 B2 — Vaccine against RSV (nucleic acid encoding pre-F protein)	Geriatric / pediatric (RSV vaccines)	Nucleic acids encoding stabilized pre-fusion RSV F protein — basis for modern RSV vaccines for older adults and infants.	[58]
5	US 10,125,172 B2 — Conformationally stabilized RSV pre-fusion F proteins	Geriatric / pediatric	Stabilized pre-F RSV F proteins for subunit RSV vaccines — improves neutralizing antibody induction.	[59]
6	Moderna (corporate patent summary for SPIKEVAX / mRNA-1273) — Moderna patent portfolio	Broad / mRNA platforms (adult & pediatric)	Moderna's core claims for mRNA vaccine technologies (mRNA constructs, LNP delivery, manufacturing).	[60]
7	WO 2021/213945 A1 — Stable multi-dose vaccine formulations	Broad / formulation stability	Stable multi-dose vaccine formulations and preservatives for biologics/mRNA — critical for pediatric and adult campaigns.	[61]
8	US 11,179,453 B2 — Hexavalent vaccine composition & toxicity studies	Pediatrics (hexavalent combination vaccines)	Toxicity and formulation data for DTwP-HepB-IPV-Hib hexavalent vaccine — supports combined pediatric schedules.	[62]
9	WO 2017/048038 A1 — Multiple-dose multivalent combination vaccine (hexavalent)	Pediatrics	Multivalent pediatric combo vaccines (D/T/P/IPV/HepB/Hib) with preservatives — programmatic dose-saving.	[63]
10	US 8,162,901 B2 — Microneedle array patch	Pediatrics & geriatrics / delivery system	Microneedle patch for transdermal vaccine delivery — enhances APC targeting, dose-sparing, and ease of use.	[64]
11	WO 2023/194712 A1 — Medicinal patch (frozen microneedles for vaccines)	Pediatrics & geriatrics	Frozen microneedle patches for thermostability and ease of use — promising for infants and adults.	[65]
12	WO 2017/123652 A1 — Microneedle compositions and methods	Pediatrics & geriatrics	Dissolvable microneedle vaccines (e.g., influenza) — supports thermostable patches and	[66]

			dose sparing.	
13	PubMed / PMC review — Global mRNA vaccine patent landscape	Broad / IP landscape	Review summarizing mRNA patent disputes, core claims, and IP holders — background for vaccine FTO.	[67]
14	Pfizer press release / FDA approval — PREVNAR 20 (PCV20)	Pediatrics & adults	Regulatory approval and IP for 20-valent conjugate vaccine (PCV20) — impacts pediatric/adult pneumococcal prevention.	[68]
15	US patent family / filings around MF59-adjuvanted subunit vaccines	Geriatric / adjuvanted protein vaccines	MF59 applied to protein subunit vaccines (e.g., COVID-19) — IP and clinical safety data.	[69]

Pharmacokinetics (PK) and Pharmacodynamics (PD) in Vaccination

Pharmacokinetics (PK) and pharmacodynamics (PD) in vaccination are deeply influenced by age-related physiological differences, and both pediatric and geriatric populations represent extremes that require specialized consideration. In pediatrics, especially neonates and infants, the liver and kidneys are functionally immature, leading to slower metabolism and reduced clearance of vaccine components. Neonates also have higher total body water and lower fat content, which can alter antigen distribution and pharmacokinetics of vaccine excipients or adjuvants. Additionally, maternal antibodies can interfere with antigen recognition and immune priming, resulting in blunted or short-lived responses to primary immunizations [70]. This explains why pediatric vaccines often use fractional doses, repeated booster schedules, and non-reactogenic adjuvants to gradually build durable immunity. Recent high-dimensional immune profiling studies [71,72] have further highlighted that immune signatures in early life can predict responsiveness, opening opportunities for individualized vaccine scheduling. In contrast, geriatric populations are affected by immunosenescence and systemic physiological decline, which manifest in PK/PD alterations. With advancing age, hepatic cytochrome P450 activity, renal clearance, and protein binding capacity all decline, leading to slower clearance of vaccine antigens or adjuvant components and altered biodistribution [73]. Coupled with immunological aging—thymic involution, reduced naïve T-cell output, impaired antigen-presenting cell function, and diminished B-cell diversity—these changes reduce vaccine efficacy, accelerate waning immunity, and increase inter-individual variability in immune response [74]. Chronic low-grade inflammation ("inflammaging") further disrupts vaccine-induced memory formation by skewing immune signaling and metabolic pathways [75]. To counter these deficits, vaccines for older adults are designed with higher antigen content (e.g., high-dose influenza vaccines), potent adjuvants (MF59, AS01), or alternative platforms such as recombinant protein subunits that better stimulate both humoral and cellular arms. Randomized controlled trials and real-world effectiveness studies [76–78] demonstrate that such pharmacological adaptations improve immunogenicity and reduce breakthrough infections in elderly populations. Thus, the pharmacological basis of vaccine design is profoundly age-dependent: pediatric vaccines focus on timing, fractionation, and safety-driven adjuvant choices to overcome immune immaturity and maternal interference, while geriatric vaccines prioritize dose escalation, adjuvant potency, and revaccination strategies to counter immunosenescence and PK/PD decline. These insights underscore the need for lifespan-tailored vaccine development, guided by emerging precision tools such as immune profiling, to optimize safety and long-term protection in both extremes of age.

Adjuvants and Delivery Systems

Modern vaccinology has evolved far beyond the use of inactivated or attenuated pathogens alone. A central pillar of this evolution is the use of **adjuvants and delivery systems**, which help fine-tune the immune response. While traditional vaccines often relied on alum-based adjuvants, today's approaches leverage next-generation tools like **saponin-based adjuvants, lipid nanoparticles (LNPs), and microneedle patches**, each playing a distinct role in improving safety, potency, and practicality. These innovations not only improve **antigen stability and immune memory** but also enable tailored solutions for **different age groups, global immunization campaigns, and emerging infectious threats**. Adjuvants and modern delivery systems are the workhorses that turn inert antigen into a robust, long-lasting immune response — they "wake up" the local innate sensors, recruit and activate antigen-presenting cells, and shape the quality, magnitude, and durability of immunity in ways that simple antigen dosing cannot accomplish. For example, saponin-based Matrix-M™ increases antigen uptake and inflammasome-linked activation of dendritic cells, producing broader antibody and T-cell responses that improved outcomes in older-adult influenza and SARS-CoV-2 protein vaccine trials [80,81]. Lipid-nanoparticle (LNP) systems used for mRNA vaccines not only protect fragile mRNA but also act as an adjuvant-like signal that promotes potent germinal-center and antibody responses after a single injection, as supported by recent mechanistic and safety reviews [82,83]. Beyond chemical adjuvants, physical delivery technologies such as dissolvable microneedle patches and high-density microarray patches target the skin's rich network of Langerhans cells and dermal dendritic cells to achieve dose-sparing, painless administration, and thermostability advantages that are especially attractive for pediatric campaigns and hard-to-reach settings. Recent phase-III and field studies of measles–rubella microarray patches report excellent immunogenicity and programmatic benefits [84,85]. Importantly, the choice of adjuvant and delivery system must be age- and condition-tailored: potent adjuvants (MF59, AS01, Matrix-M) can meaningfully augment responses in older adults with immunosenescence, whereas pediatric formulations often prioritize minimal reactogenicity and schedule compatibility while still seeking improved priming via safe adjuvantation or intradermal approaches [86,87]. Finally, emerging work combines systems-biology profiling with novel adjuvants and delivery

routes to predict who will respond best and to design formulations that steer immunity (for example, toward mucosal IgA vs systemic IgG), an approach that promises more precise, age-adapted vaccines in the near future [88,89].

Age-Specific Use of Vaccine Adjuvants: Pediatric and Geriatric Considerations

The selection of appropriate vaccines and adjuvants varies considerably between pediatric and geriatric populations due to differences in immune system maturity and senescence. In children, vaccines are designed to elicit strong priming responses with minimal reactogenicity, often relying on aluminium salts or non-adjuvanted formulations to ensure safety. Newer modalities, such as microneedle patches and lipid nanoparticle (LNP)-based mRNA vaccines, have shown promising safety and immunogenicity in younger cohorts. Conversely, in older adults, where immune responses are typically blunted, the use of potent adjuvants such as MF59, AS01, or CpG-1018 significantly enhances both humoral and cellular immunity. High-dose antigen formulations are also employed to overcome immune deficits. Recent clinical and translational studies highlight the critical role of tailored adjuvant strategies to optimize protective efficacy across different age groups.

Table 3: Comparative analysis of minimal adjuvant use in pediatrics versus potent adjuvant strategies in geriatrics.

Age Group	Vaccine / Adjuvant	Study Focus & Findings	Ref.
Pediatric	DTaP with Alum	Aluminium salts remain safe and effective, minimal reactogenicity in infants.	[90]
Pediatric	Hepatitis B (Alum)	Alum-adjuvanted HBV vaccine shows strong neonatal antibody priming.	[91]
Pediatric	Microneedle measles patch	Intradermal delivery without strong adjuvants induces comparable responses.	[92]
Pediatric	mRNA COVID-19 (LNPs, reduced dose)	Lower mRNA doses + LNPs well tolerated, strong neutralization in 5–11 yrs.	[93]
Pediatric	Rotavirus (oral, no adjuvant)	Demonstrated effective mucosal priming in infants.	[94]
Pediatric	Inactivated polio + alum	Safe immune boosting with minimal adjuvant load.	[95]
Pediatric	Influenza LAIV (no adjuvant)	Effective pediatric protection via mucosal immunity.	[96]
Geriatric	High-dose influenza (4× antigen)	Demonstrated superior immunogenicity in ≥65 yrs.	[97]
Geriatric	Influenza + MF59	MF59 improves both antibody titers and T-cell responses.	[98]
Geriatric	Shingrix (AS01B)	Strong CD4+ T-cell boosting, sustained ≥7 yrs.	[99]
Geriatric	SARS-CoV-2 NVX-CoV2373 (Matrix-M)	Matrix-M boosts neutralizing titers, elderly subgroup well covered.	[100]
Geriatric	HBV (Heplisav-B, CpG-1018)	Superior seroprotection vs. alum-adjuvanted vaccines.	[101]
Geriatric	COVID-19 mRNA (BNT162b2, higher dose)	Dose-sparing less effective in elderly; full dose required.	[102]
Geriatric	RSV prefusion F + AS01E	RCT shows improved protection in ≥60 yrs.	[103]
Geriatric	Cancer + influenza vaccine with CpG	Experimental trial: CpG boosts T-cell function in immunocompromised elderly.	[104]

Clinical and Regulatory Perspectives

Vaccination policies for children and older adults share the same overarching goal—protecting populations while minimizing risks—but the clinical details and regulatory frameworks differ because of age-specific biology, risks, and care settings.

Vaccination schedules and policy frameworks

Global and national schedules provide age-tailored recommendations on which vaccines, doses, and intervals should be routine. The **World Health Organization (WHO)** issues consolidated guidance across the lifespan, including recommendations for special circumstances such as outbreaks or supply shortages, which often influence pediatric and adult vaccination decisions [105]. In the United States, the **CDC's Advisory Committee on Immunization Practices (ACIP)** produces annual schedules for children, adolescents, and adults. These schedules specify age-based vaccine use, highlight preferential products for older adults (such as high-dose or adjuvanted influenza vaccines), and include notes for special situations like pregnancy, immunocompromise, or recent transfusions [106–108].

Age-specific contraindications and precautions

Before each vaccine dose, clinicians must carefully screen for contraindications and precautions. In children, these often relate to prior severe allergic reactions, immune deficiencies that restrict live vaccine use, or other specific pediatric considerations. Guidance from the **American Academy of Pediatrics and CDC** provides structured checklists for such assessments [109]. For older adults, the contraindications are similar, but precautions more often involve comorbidities, frailty, or interactions with immunosuppressive therapies. Choosing the right product—for instance, adjuvanted influenza vaccines for frail seniors—is central to safe practice [107,108].

Pharmacovigilance and safety monitoring

Detecting and responding to vaccine safety signals is a cornerstone of trust in immunization. The WHO's global pharmacovigilance platform **VigiBase** collects spontaneous reports from countries to identify rare or unexpected adverse events [110]. In the U.S., passive systems like **VAERS** and active networks like the **Vaccine Safety Datalink (VSD)** complement each other: VAERS helps flag unexpected

signals, while VSD enables near real-time monitoring and follow-up [111]. Evidence shows that active surveillance remains underdeveloped in many low- and middle-income countries, highlighting the need for greater investment in representative and rapid-response monitoring [112].

Recent safety experiences

The COVID-19 vaccine rollout underscored the importance of agile pharmacovigilance. Rare adverse events—such as myocarditis in younger males or Guillain–Barré syndrome in older groups—were identified through combined passive and active systems, followed by rapid evaluation to update recommendations and risk–benefit communications [111,113]. Similar monitoring continues for both children (e.g., febrile seizures, intussusception) and older adults (e.g., stroke, thrombotic events), demonstrating how surveillance adapts to different age-related risks [112,113].

Implications for practice and policy

For clinicians, this means adhering to WHO and national schedules [105–108], screening patients at every visit [109], choosing age-preferred products [107,108] and reporting suspected adverse events promptly [110,111]. For policymakers, the priorities are clear: strengthen active surveillance systems, ensure inclusion of vulnerable groups like frail elderly and very young infants, and maintain transparent communication of findings [112–114]. Together, these measures ensure that vaccination programs remain both effective and trusted across the lifespan.

Challenges and Future Directions

Even with the remarkable progress in vaccine science, protecting the youngest and oldest in our communities still comes with challenges. One of the most persistent is vaccine hesitancy. Parents may worry about the safety or long-term effects of childhood vaccines, while many older adults remain unsure whether vaccines will work for them, especially if they already live with chronic illnesses or are taking multiple medications [115,116]. These concerns show that building trust, listening to fears, and providing clear and empathetic communication are as important as the science itself. At the same time, researchers are realizing that a “one-size-fits-all” approach to vaccination doesn’t always work. Each person’s immune system—shaped by age, genetics, past infections, and overall health—responds differently to vaccines. New tools from systems immunology are helping to map these differences, and early studies suggest that immune “signatures” may soon allow us to predict who needs a stronger vaccine dose, a specific adjuvant, or a different schedule altogether [117,118]. On the technology front, the last few years have brought new platforms into the spotlight. mRNA vaccines, proven during the COVID-19 pandemic, are now being tested for children and older adults, with researchers working hard to fine-tune the balance between safety, dosage, and effectiveness [119]. Nanoparticle-based delivery systems—including lipid nanoparticles and virus-like particles—are also being developed to make vaccines longer-lasting and more powerful [120]. Meanwhile, thermostable vaccines for children could change the game in low-resource settings, eliminating the need for a strict cold chain and making lifesaving vaccines more accessible worldwide [121]. Looking ahead, experts are talking about a lifelong vaccination approach—moving beyond the idea that vaccines are mostly for kids. In this vision, immunization becomes a continuous process, with timely boosters, age-tailored formulations, and vaccine literacy woven into every stage of life. By making vaccination a part of healthy aging as much as healthy childhood, we can build resilience across the whole lifespan [122].

CONCLUSION

Vaccination at the extremes of age requires a deliberate balance between immunological needs, pharmacological design, and safety considerations. Pediatric vaccines focus on gradual immune priming through fractional dosing, booster schedules, and minimally reactogenic adjuvants, while geriatric vaccines prioritize antigen intensification, potent adjuvantation, and simplified schedules to overcome immunosenescence. Advances in mRNA technology, nanoparticle delivery, and microneedle platforms demonstrate the promise of next-generation solutions for both groups. Regulatory frameworks and pharmacovigilance remain central to ensuring safety and public confidence. Ultimately, the future of vaccinology lies in precision and personalization—using immune profiling, systems biology, and innovative delivery systems to design age-adapted vaccines. By embracing lifespan-tailored strategies, vaccination can continue to protect vulnerable populations effectively, reinforcing its role as a cornerstone of global health.

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