Assessing Screening Policies for Childhood Obesity

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Abstract

To address growing concerns over childhood obesity, the United States Preventive Services Task Force (USPSTF) recently recommended that children undergo obesity screening beginning at age 6 [1]. An Expert Committee recommends starting at age 2 [2]. Analysis is needed to assess these recommendations and investigate whether there are better alternatives. We model the age- and sex-specific population-wide distribution of body mass index (BMI) from birth through age 18 using data from the National Longitudinal Survey of Youth [3]. The impact of treatment on BMI is estimated using the targeted systematic review performed to aid the USPSTF [4]. The prevalence of hypertension and diabetes at age 40 are estimated from the Panel Study of Income Dynamics [5]. We fix the screening interval at 2 years, and derive the age- and sex-dependent BMI thresholds that minimize the adult disease prevalence, subject to referring a specified percentage of children for treatment yearly. We compare this optimal biennial policy to biennial versions of the USPSTF and Expert Committee recommendations. Compared to the USPSTF recommendation, the optimal policy reduces the adult disease prevalence by 3% in relative terms at the same treatment referral rate, or achieves the same disease prevalence at a 28% reduction in treatment referral rate. If compared to the Expert Committee recommendation, the reductions change to 6% and 40%, respectively. The optimal policy treats mostly 16 year olds and few children under age 14. Our results suggest that adult disease is minimized by focusing childhood obesity screening and treatment on older adolescents.

Introduction

The obesity rate of U.S. children ages 2-19 has tripled since 1980 and is approximately 17% [6]. Obesity in children, which is defined as exceeding the 95th percentile of the sex- and age-based body mass index (BMI) distributions tabulated by the Centers for Disease Control and Prevention (CDC) [7], is associated with high lipid concentrations and blood pressure [8] and with adult obesity [9], which carries an increased risk of diseases such as hypertension and type 2 diabetes [10, 11], and of all-cause mortality [12].

Two complementary approaches have been put forth to address this problem: a targeted approach consisting of obesity screening and intervention, and a universal approach that focuses on better nutrition and more physical activity [13], and involves schools, families, communities, and the food industry. Although a comparison of the costs and benefits of these two approaches is needed, the current study focuses on the targeted approach.

To combat the high rate of childhood obesity in the U.S., both the US Preventive Services Task Force (USPSTF) [1], with the aid of a targeted systematic review of the efficacy of comprehensive (dietary, physical activity and behavioral counseling components) childhood obesity treatment [4], and an Expert Committee comprised of representatives from 15 professional organizations [2], recommend childhood BMI screening (by clinicians in a primary care setting) and intervention for obesity.

Childhood obesity screening programs (as distinct from monitoring programs that assess the prevalence of childhood obesity in a particular population [14]) are defined by three elements: the age at which assessment begins, the frequency of assessment, and the threshold for referring individuals to treatment. Conflicting recommendations have been proposed for the starting age: age 6 for USPSTF [1] vs. age 2 for the Expert Committee [2]. Less guidance is available about the frequency - the Expert Committee proposes annual screening and the USPSTF does not recommend a screening frequency – although if BMI measurements are provided during routine pediatric visits or at schools [14], the natural frequency is either every year or every 2 years. The recommended thresholds for both the USPSTF and Expert Committee recommendations are equal to the 95th percentile of the CDC distributions that defines obesity, which implicitly assumes that neither the benefits of treatment nor the tradeoffs between sensitivity and specificity possess a strong dependence on age.

The goal of the present study is to investigate whether there are more effective childhood obesity screening policies than those proposed by the USPSTF and Expert Committee. Toward that end, we fix the frequency of screening at every 2 years, and derive the age- and sex-dependent treatment thresholds for ages $2, 4, \ldots, 16$ that minimize the disease prevalence at age 40 subject to referring for treatment a specified percentage of children each year. This essentially allows us to jointly optimize the starting age and the thresholds because if an extremely high threshold is chosen at a given age, then no treatment is applied – and hence no assessment is needed – at that age. We compare the performance of this optimal biennial screening policy to the performance of the biennial version of the USPSTF recommendation that screens for obesity at ages $6, 8, \ldots, 16$, and the biennial version of the Expert Committee recommendation that screens at ages $2, 4, \ldots, 16$.

Methods

Overview. The detailed analysis used to justify and calibrate the mathematical model, and derive the optimal screening policy, appears in a companion paper [15], and is briefly summarized here. Using biennial BMI data from 3164 children from the National Longitudinal Survey of Youth (NLSY) samples [3], we model the evolution of the probability density function (pdf) of BMI for all U.S. children in the absence of treatment. Each child receives a weight such that the weighted sample of the 3164 children represents all children born between 1970 and 1988 to women ages 21 to 31 who were present in the U.S. in 1979, and all of our analyses are on the weighted sample. We use the pooled analysis of three comprehensive moderate- or high-intensity behavioral interventions [4] to estimate the impact of treatment. We estimate the disease prevalence of hypertension and diabetes when they reach age 40 using Panel Study of Income Dynamics (PSID) data [5] containing the BMI at ages 18 and 40 and the presence or absence of hypertension or type 2 diabetes by age 40 for 747 people. Dynamic programming is used to derive the age- and sex-specific thresholds that minimize the prevalence of disease at age 40 subject to referring for treatment a specified percentage of children each year.

Evolution of the Population-wide BMI Distribution. The basic system state for our model is the population-wide probability density function of the BMI at ages 0,2,. . . ,18, and the dynamics of this process in the absence of treatment are constructed using biennial BMI data from 3164 children ages 0,2,. . . ,18 from the NLSY samples [3]. Exploratory data analysis reveals that it is reasonable to assume that the data possess the first-order Markov property (i.e., BMI at age $t + 2$ depends only on the BMI at age t and not on the BMI at ages $0, 2, \dots, t - 2$), and that a Box-Cox transformation (which is commonly used to make data look more like a normal distribution) of BMI levels follows a normal distribution, as do the increments of the transformed BMI. We assume that the distribution at age 0 is a skew normal distribution (which is a generalization of the normal distribution that allows for some asymmetry in the shape of the probability density function), and assume that the increment of transformed BMI from age t to age $t + 2$ is a normal random variable with mean and variance that depend on the age t and the transformed BMI level at age t.

Impact of Treatment. As a result of analyzing several alternative assumptions (§4.3 of [15]), we assume that the impact of treatment on the Box-Cox transformed BMI is a random variable that is independent of age, sex and pre-treatment BMI level. The mean and variance of this random variable is estimated from the three comprehensive moderate- to high-intensity intervention programs considered in Table 1 of the targeted systematic review that was performed to aid the USPSTF [4]. These data provide aggregate results on the effect of treatment and do not allow us to reliably estimate the dependence of treatment on the gender, age or pre-treatment BMI level. However, even though the impact of treatment on the Box-Cox transformed BMI is assumed to be independent of age, sex and pre-treatment level, the impact of treatment on the untransformed BMI is not independent of age, sex and pre-treatment BMI level. Indeed, the analysis in §3 of the Appendix of [15] shows that our model accurately captures the fact that the reduction in untransformed BMI is increasing in the pre-treatment level of BMI for these three reviewed programs (see Fig. 4 of [15]). Analysis in §3 of the Appendix of [15] also shows that this independence assumption leads to a larger z-BMI (which is defined by converting the CDC growth charts in [7] into standard normal distributions, and then expressing z-BMI as the number of standard deviations above or below the mean) reduction for ages 6,8,10 than for ages 12,14,16, which is consistent with the studies summarized in [16]. Because clinicians are unlikely to withhold referral of treatment due to previously failed attempts at treatment (recall that the duration of treatment is much shorter than the screening interval), we assume that individuals in our model can receive treatment more than once in their childhood. We further assume that children receiving treatment at more than one age have treatment efficacies that are statistically independent (see the Discussion for implications of this assumption).

Adult Disease Prevalence. We estimate the disease prevalence of hypertension and type 2 diabetes at age 40 using three data sets that measure BMI from three different sets of individuals: longitudinal data from NLSY containing the BMI at ages 0,2,...,18 for 3164 children [3], longitudinal data from PSID containing the BMI at ages 18 and 40 and the presence or absence of hypertension and diabetes at age 40 for 747 people, and the cross-sectional BMI data for ages $18, 19, \ldots, 40$ for 7966 adults in the National Center for Health Statistics (NHANES) data set [17]. All three data sets have sample weights that describe how representative each of the people are in the general population, and all analyses are carried out on weighted samples. We make the key assumption that the likelihood of having hypertension or diabetes at age 40 is a function of the average BMI over the first 40 years of life. We use the NHANES data to estimate the weight so that the weighted average of the BMI at ages 18 and 40 equals the average BMI over ages 18,19,. . . ,40. We then use logistic regression to predict the disease prevalence at age 40 in terms of an independent variable which is $\frac{18}{40}$ times the average BMI over ages 0,2,. . . ,18 in NLSY plus $\frac{22}{40}$ times the weighted average (using the weight from the NHANES analysis) of the BMI at ages 18 and 40 in the PSID data. We simulate 10^6 individuals (i.e., we randomly sample BMI at ages 0,2,. . . ,18 from the NLSY data set, and BMI at ages 18 and 40 and disease at age 40 from the PSID data set, where the sampled BMI at age 18 from the PSID data set is restricted to equal the BMI at age 18 from the NLSY data set) using the resulting regression coefficients to compute the adult disease prevalence for any arbitrary threshold policy, including the optimal policy and the USPSTF and Expert Committee recommendations.

The Optimal Threshold Policy. We use dynamic programming to optimize over the class of threshold policies, where the threhold level varies with age and sex. Anyone with a BMI value over the threshold is referred for treatment for ages 2,4,. . . ,16, and a fixed proportion of referrals undergo treatment; we refer to this proportion as the treatment compliance rate. We choose the optimal thresholds to minimize the disease prevalence at age 40 (computed using the logistic regression coefficients derived earlier) subject to a constraint on the percentage of all children aged 2,4,. . . ,16 who screen positive (and hence are referred to treatment) each year. Because screening costs are negligible compared to treatment costs (at least if BMI is measured during routine pediatric primary care visits), and because the treatment compliance rate is fixed, the percentage of children who screen positive is proportional to the total annual treatment costs. By solving this optimization problem for many different values of the allowable percentage of children who screen positive each year, we generate tradeoff curves of disease prevalence vs. percentage referred for treatment for the two diseases and two sexes.

Results

We compute disease prevalence vs. percentage referred for treatment (Table 1, Fig. 1) for three policies: the biennial version of the USPSTF policy (i.e., using the 95$^{\text{th}}$ percentile of the CDC BMI distributions for ages 6,8,. . . ,16), the biennial version of the Expert Committee policy, which starts at age 2 rather than age 6, and the optimal biennial policy (as explained below, the policy we refer to as optimal is nearly, but not exactly, optimal), which sweeps out a tradeoff curve by re-solving the optimization problem for various values of the percentage who screen positive.

We begin by assuming 100% treatment compliance: everyone who screens positive undergoes treatment. Compared to the biennial USPSTF policy, the relative reduction in disease prevalence achieved by the optimal policy is 3% (2.0% for male hypertension, 3.2% for male diabetes, 4.4% for female hypertension, 4.3% for female diabetes) at the same percentage of children referred for treatment (the absolute reductions in disease prevalence are much smaller: 0.41% for male hypertension, 0.18% for male diabetes, 0.89% for female hypertension and 0.20% for female diabetes), or generates the same disease prevalence with a 28% (28.2% for males, 28.1% for females) reduction in percentage referred for treatment. The large discrepancy between these two reductions is due to the flatness of the optimal tradeoff curve (Fig. 1). Comparing the USPSTF policy and Expert Committee policy shows that beginning screening at age 2 rather than age 6 increases the percentage referred for treatment by 35.3% for females and 37.4% for males, while achieving a relative reduction in disease prevalence by 1.2% for females and $< 1\%$ for males. Relative to the Expert Committee policy, the optimal policy achieves a 6% relative reduction in disease prevalence at the same treatment level, or a 40% reduction in treatment referrals at the same disease prevalence.

Relative to no screening, the optimal policy with the percentage referred for treatment equal to that of the biennial USPSTF policy achieves a relative reduction in disease prevalence of 8.1% for male hypertension, 13.8% for male diabetes, 17.8% for female hypertension, and 21.3% for female diabetes. As an upper bound, the optimal policy when 25% of children ages 2,4,...,16 are referred for treatment each year achieves a relative (i.e., relative to no screening) reduction in disease prevalence of 15.6% for male hypertension, 24.5% for male diabetes, 35.0% for female hypertension, and 37.0% for female diabetes.

We present the results for the case of 50% compliance rate in Fig. 1. Compared to the USPSTF and Expert Committee policies, the optimal policy achieves a 1.5% and 3.0% relative reduction in disease prevalence at the same treatment level, and a 21.8% and 35.2% reduction in treatment referrals at the same disease prevalence. More generally, extensive computations suggest that the relative reduction in disease prevalence (at the same treatment level) under imperfect compliance is slightly less than the compliance rate times the relative reduction in the 100% compliance case, and the relative reduction in treatment referrals (at the same disease prevalence) is 15-30% less than it is under 100% compliance.

The optimal biennial policy that is reported in Fig. 1 and Table 1 is actually optimal only among all policies that screen at ages 12,14,16. However, numerical results in [15] allow us to conjecture that the policy that optimally screens at ages 12,14,16 is very nearly optimal among all policies that screen at ages 2,4,...,16. The optimal policy that screens at ages 12,14,16 achieves its improvements over the biennial USPSTF and biennial Expert Committee policies by aggressively (i.e., with thresholds well below the CDC's obesity thresholds) treating older adolescents. The majority ($\approx 51\%$ for females and $\approx 70\%$ for males) of treatment occurs at 16 years old (including males who fall under the 85th CDC percentile, which is the overweight threshold), and very few ($\approx 1.7\%$) males under 14 years old are treated (Fig. 2).

Discussion

Childhood obesity screening and treatment policies investigate two interrelated decisions: how many total children should be treated and exactly which children to treat. The USPSTF and Expert Committee both state who should be treated: children exceeding the 95$^{\text{th}}$ percentile of the CDC's BMI distributions (which corresponds to roughly 15% of children, due to the tripling of obesity over the last several decades), starting at ages 6 and 2, respectively. The question of how many total children to treat also depends on the frequency of screening. While the USPSTF does not recommend a screening frequency, the Expert Committee recommends annual screening. We restrict our analysis to the biennial versions of the USPSTF recommendations, the Expert Committee recommendations, and the optimal policy, but comment on the merits of annual screening below.

Our main result is that the optimal biennial policy, which chooses age-dependent (and sex-dependent) thresholds to optimize the tradeoff between the prevalence of age-40 disease (hypertension and diabetes) and the percentage of children referred for treatment (which is proportional to the annual treatment costs), can either achieve a relative reduction in disease prevalence of 3% at the same percentage of treatment referrals as the biennial USPSTF policy, or generate the same disease prevalence as the biennial USPSTF policy at a 28% relative reduction in treatment referrals, under the assumption of 100% treatment compliance. If the optimal policy is compared to the biennial Expert Committee policy, the reductions increase from 3% to 6% and from 28% to 40%. If compliance is imperfect, then the relative reduction in disease prevalence is slightly less than the compliance rate times the relative reduction under 100% compliance, and the relative reduction in treatment referrals is 15-30% less than the relative reduction under 100% compliance. As far as who to treat, the optimal policy deviates dramatically from the other two policies: it achieves these improvements by treating mostly 16 year olds, and treating few males under 14 years old (Fig. 2). This deviation is primarily due to the fact that, in the absence of treatment, many children who are obese at age 10 or younger are no longer obese at age 18 [18].

Because of the noisy relationship between adult obesity and adult disease, our decision to use the prevalence of adult disease rather than the prevalence of adult obesity as the health outcome is a conservative one with respect to our main results. For example, compared to the USPSTF policy, the optimal biennial policy achieves a relative reduction in adult (i.e., age-40) obesity prevalence of 14.7% at the same percentage of treatment referrals as the biennial USPSTF policy, which is nearly 5 times greater than the 3% achieved for disease prevalence.

Because the optimal tradeoff curves do not greatly deviate from straight lines (the absolute value of the slope of the curves, which is a measure of cost-effectiveness, decreases by an average of only 72% as the percentage referred for treatment increases from 0% to 25%), it is difficult to make any recommendations regarding how many children to treat. However, even at the percentage referred for treatment that is 28% lower than that of the USPSTF policy (but achieves the same disease prevalence), the BMI thresholds at age 16 are at the 82nd-83rd percentiles, which would lead to the treatment not only of all obese and overweight 16 year olds, but also some below the conventional threshold for overweight (i.e., 85th percentile). At the percentage referred for treatment of the biennial USPSTF policy, the optimal policy sets the BMI threshold for 16 year old males at the 71st percentile, which corresponds to treating 52.1% of 16 year old males; cost and treatment capacity considerations aside, this raises the question of whether a universal school-based intervention would be more practical than treating over half of 16 year old males. A modeling study predicts that, should effective universal interventions be available, they would provide greater health benefits than screening-guided interventions, although costs were not compared [18] (see [19] for a recent comparison of the cost-effectiveness of various obesity interventions).

Finally, if annual screening were used instead of biennial screening, the percentage referred for treatment would approximately double for the Expert Committee policy and nearly double for the USPSTF policy. The optimal thresholds that achieve this level of treatment referral would screen positive even more children who are not defined as overweight, compared to the values in Fig. 2. Moreover, by Fig. 1, annual screening would likely move the optimal policy to a flatter portion of the tradeoff curve, where the marginal health benefits from treatment referral are smaller.

Limitations of the Study. While the mathematical model appears to capture all of the salient features of the problem, the biggest limitations of our study are due to a paucity of data, particularly regarding the effects of treatment. In practice, many children will refuse treatment (even if it is free), and compliance for those who initiate treatment will not be perfect, and is likely to be lower than the compliance achieved in clinical trials. Because there are no compliance data, we assume that compliance is independent of pre-treatment BMI level, age and screening policy, which allows is to easily incorporate the effects of imperfect compliance (Fig. 1). Data on how the compliance rate varies with age, sex and pre-treatment BMI level would allow for a refinement of our results.

The childhood BMI data in the absence of treatment by and large possess the Markov (i.e., memoryless) property [15], where the population-wide BMI distribution at age $t + 2$ depends on the BMI distribution at ages $2,4,\ldots,t$ only via the BMI distribution at age t. However, we also assume that the Markov property holds in the presence of treatment; i.e., if someone has a certain BMI at age t, then his future BMI does not depend on whether or not he received treatment prior to age t. Treatment effects are transient in some studies [21] and more durable in others [16], and this issue deserves further investigation (particularly if a treatment program was compared to a prevention program, because the impacts of a treatment program may lessen over time whereas the impacts of a population prevention program may persist or even increase over time as the effects of changed environments, cultural norms and policies take hold). One implication of the Markov property is that children who are treated at more than one age have treatment efficacies that are statistically independent. If the treatment efficacies for a given child across different ages are positively correlated, then we may be overestimating the effect of multi-age treatment because children who do not respond well to treatment are more likely to exceed the BMI screening threshold 2 years later. Interestingly, the policy that screens only at age 16, which is not subject to this bias, outperforms the biennial USPSTF policy for hypertension (although not for diabetes) [15].

Although our model is able to accommodate a treatment effect that depends on age and pre-treatment BMI level, very little data exist to estimate these dependencies. As discussed earlier, sensitivity analysis in [15] reveals that a strong age-dependence (i.e., younger children achieve 40% higher BMI reduction than older children) can impact our qualitative conclusions. In contrast, sensitivity analysis in [15] shows that our qualitative conclusions are unaffected if children above the 97th percentile of the CDC BMI distributions achieve much (e.g., 3-fold) larger BMI reductions than those below the 97th percentile, or if disease prevalence depends on average lifetime z-BMI (i.e., the number of standard deviations above or below the mean BMI, after transforming the BMI distribution into a normal distribution) rather than average lifetime BMI.

The last several shortcomings in the data are unrelated to treatment. The NLSY BMI data cover children born between 1970-1988, and the PSID data cover children born during 1968-2009. Because childhood obesity has tripled since 1980 [6], our results may underestimate the percentage referred for treatment and the steepness of the tradeoff curves (because more children will be at higher risk). In addition, the NLSY data set is not large enough to look at other subgroups (e.g., race) beyond sex. Also, the PSID data, which tracks disease prevalence at age 40, was used because of its relatively large sample size. However, most diabetes and hypertension costs and consequences emerge after this age. Using data with an older adult age may have generated larger benefits from screening and treatment.

Finally, by far the most difficult data to obtain relate to the lifetime effects of BMI on adult disease, which perhaps requires a longitudinal study of five or six decades. In the absence of additional studies on this topic, we believe that it is prudent to employ our key assumption that adult disease depends on the average lifetime BMI (or z-BMI). Sensitivity analysis in [15] shows that this assumption – compared to the alternative assumption that adult disease depends on childhood BMI only via BMI at age 18 – is conservative with respect to the argument that the optimal policy outperforms the biennial USPSTF policy.

Conclusion

Although treatment efficacy and compliance data are sparse, and the lifetime effects of obesity on adult disease are not well understood, our analysis suggests that it is wasteful to use thresholds – such as the 95th percentiles of the CDC distributions recommended by USPSTF and the Expert Committee – that do not account for how the sensitivity and specificity (with respect to adult disease) of these thresholds vary with age. More specifically, our results suggest that treating obese and overweight older adolescents (e.g., 16 year olds) is more effective at reducing adult hypertension and diabetes than treating obese children of all ages. Our study also provides a framework with which to analyze more detailed treatment data that are collected in the future.

Our mathematical modeling study is intended to inform the debate on the appropriate screening policy for childhood obesity, and more generally on the role that targeted screening and treatment has in the larger response to the obesity epidemic [13, 19]. The USPSTF and

Expert Committee policies have not been previously analyzed in terms of suboptimality (the focus of the present paper) or supply-side feasiblity (i.e., over 5M and 10M children, respectively, would be referred for treatment annually under these two policies). However, our model captures only some of the aspects of this very complex issue, and our results do not imply that pre-adolescents should not be screened and treated for obesity. Rather, in our view, the results suggest that policymakers in this area need to more clearly articulate and justify their rationale for screening and treating children between the ages of 2 and 12. While other arguments may exist that do not rely solely on BMI reduction – e.g., the social and psychological effects of childhood obesity, the possibility that younger children may have higher treatment compliance than older adolescents (sensitivity analysis in [15] provides a rough assessment of such an argument: the reduction in BMI due to treatment for children ages 6-10 needs to be 60% higher than our estimates, with no change for children ages 12-16, in order for the biennial USPSTF policy to achieve the same performance as the optimal policy), that treatment for younger children also instills other good lifestyle choices, such as not smoking, that provide benefits later in life [20], that the act of screening itself signals to the patient and parent the importance of this health indicator, or even the simplicity of the proposed guidelines – a persuasive rationale has yet to be made.

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Policy			Males		
Name	Ages	Percentile of Thresholds	% Referred for Treatment	Hypertension Prevalence	Diabetes Prevalence
No screening			0.00%	22.14%	6.36%
USPSTF	6,8,...,16	95th	10.27%	20.76%	5.66%
Expert Committee	2,4,...,16	95th	14.11%	20.64%	5.60%
Optimal	12,14,16	optimal	10.27%	20.35%	5.48%
Optimal	12,14,16	optimal	14.11%	19.85%	5.27%
Optimal	12,14,16	optimal	25.00%	18.69%	4.80%

Policy			Females		
Name	Ages	Percentile of Thresholds	% Referred for Treatment	Hypertension Prevalence	Diabetes Prevalence
No screening			0.00%	23.50%	5.68%
USPSTF	6,8,...,16	95th	8.50%	20.20%	4.67%
Expert Committee	2,4,...,16	95th	11.51%	19.95%	4.62%
Optimal	12,14,16	optimal	8.50%	19.31%	4.47%
Optimal	12,14,16	optimal	11.51%	18.33%	4.24%
Optimal	12,14,16	optimal	25.00%	15.27%	3.58%

Table 1: For selected policies and for 100% treatment compliance, the percentage of children ages $2, 4, \ldots, 16$ referred for treatment each year, and the hypertension and diabetes prevalences (expressed as percentages) at age 40.

Figure Legends

Fig. 1: Tradeoff curve of disease prevalence at age 40 vs. percentage of children ages $2, 4, \ldots, 16$ that are referred for treatment each year, for the optimal biennial screening policy, under 50% compliance (- - -) and 100% compliance (—). The "+" and "x" denote the biennial version of the USPSTF recommendation under 50% and 100% compliance, respectively, and the "$\diamond$" and "$\circ$" denote the biennial Expert Committee policy under 50% and 100% compliance, respectively. **(a)** hypertension among males; **(b)** diabetes among males; **(c)** hypertension among females; and **(d)** diabetes among females.

Fig. 2: Optimal screening thresholds for the three-age screening policy at ages (12,14,16), expressed as the percentile of the sex- and age-based BMI distributions tabulated by the CDC (Kuczmarski *et al.* 2000), for two cases: the percentage of children referred for treatment equals that of the biennial USPSTF policy (— for males and -x- for females) and the disease prevalence equals that of the biennial USPSTF policy (··· for males and ·x· for females). The biennial USPSTF policy uses the 95^{th} percentile for ages 6,...,16.

Figure 1: Performance of Policies

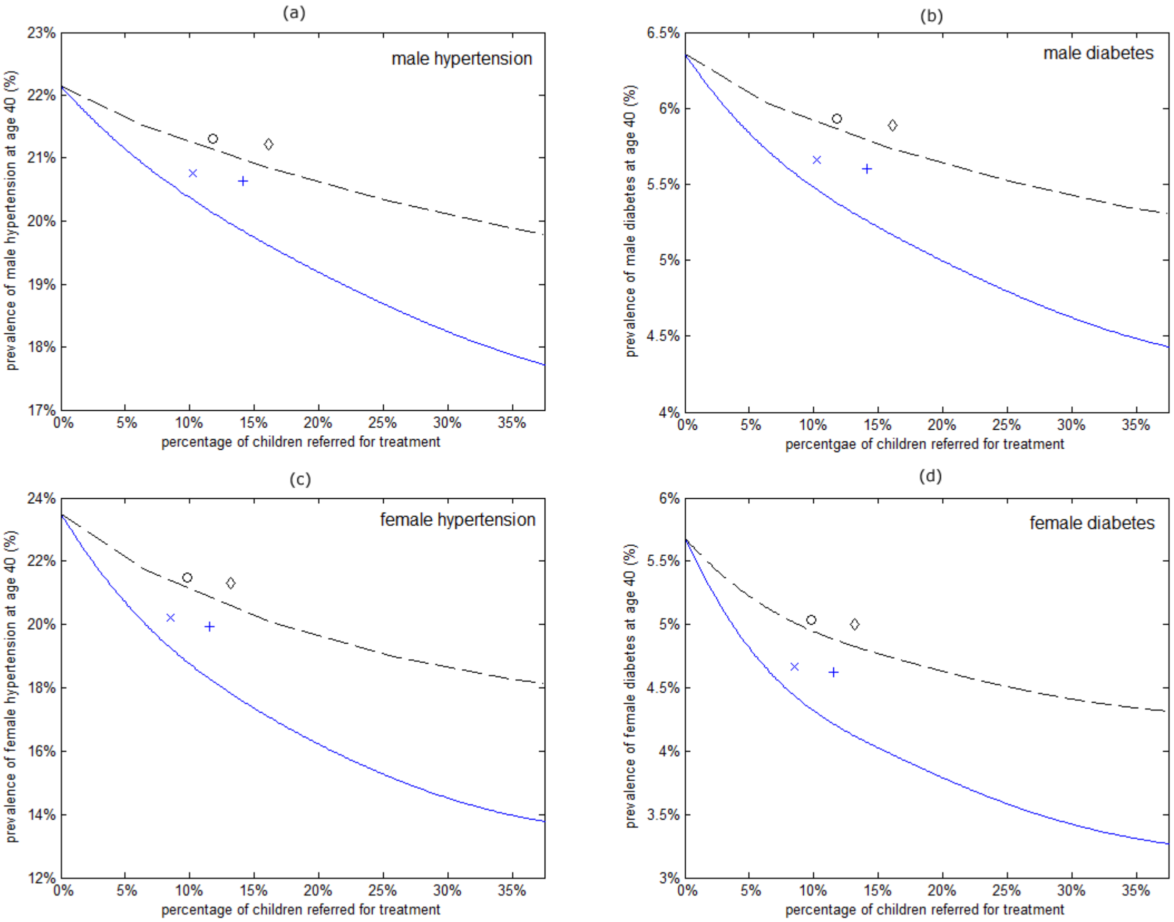

Figure 2: Optimal Screening Thresholds