Environmental Interventions to Prevent Falls in Community-Dwelling Older People

A Meta-Analysis of Randomized Trials

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Objective: This study seeks to determine the efficacy of environmental interventions in reducing falls in community-dwelling older people. Method: A systematic review and meta-analysis of randomized trials was performed. Results: Pooled analysis of six trials (N = 3,298) demonstrated a 21% reduction in falls risk (relative risk [RR] = 0.79; 0.65 to 0.97). Heterogeneity was attributable to the large treatment effect of one trial. Analysis of a subgroup of studies with participants at high risk of falls (four trials, n = 570) demonstrated a clinically significant 39% reduction of falls (RR = 0.61; 0.47 to 0.79), an absolute risk difference of 26% for a number needed to treat four people. Discussion: Home assessment interventions that are comprehensive, are well focused, and incorporate an environmental-fit perspective with adequate follow-up can be successful in reducing falls with significant effects. The highest effects are associated with interventions that are conducted with high-risk groups.

Keywords: accidental falls; home visits; home assessment; occupational therapy; systematic review
The consequences of falling include injury, fear of falling in daily life activity, and restricted mobility and activity associated with loss of independence and admission to residential care. Falls occur in the context of the environment, but there is controversy over the effectiveness of home safety audits. National guidelines (National Institute for Clinical Excellence [NICE], 2004; Todd, Ballinger, & Whitehead, 2007) support home safety audits as a valid intervention and recommend policy and funding to support home hazard assessment and safety intervention. This approach has emerged as a strategy supported by the most recent Cochrane systematic review of fall trials (Gillespie et al., 2005). However, recent published reviews (Chang et al., 2004; Lord, Menz, & Sherrington, 2006; Tse, 2005) have been of the opinion that the current evidence is inconclusive. Confusion is reflected in current practice where medical and health professionals are not clear about the need for home hazard assessment or what constitutes best practice (Rubenstein, 2006).

General medical practitioners, gerontologists, and rehabilitation specialists are in a strong position to identify older people at risk of falls and refer them to local community services such as occupational therapy. However, there is uncertainty over which older people would benefit the most from this intervention, and many practitioners continue to doubt it is a useful strategy to prevent falls. One trial showed a home visit intervention resulted in decreased falls in the community as well as at home (Cumming et al., 1999). This raised concerns with interpretation of results and issues about the intervention process itself and whether or not it has a capacity to enable older people to generalize safety skills from the home situation.

This study reports a pooled analysis of environmental randomized trials to measure overall effects on falls prevention. The aim is to determine the efficacy of environmental interventions in falls prevention and increase the precision of known results.

Method

Search Strategy and Selection Criteria

Electronic databases, including Medline, Embase, and CINAHL, from January 1990 to July 2007, were searched. We also manually searched citation indices and bibliographies of review articles and the located articles.

Search strategies used were the Cochrane highly sensitive search strategy for randomized trials (Clarke & Oxman, 2003); the falls and elderly search strategy by Gillespie et al. (2005), which includes aged, older, senior
or seniors, and elderly in its search terms; and specific search strategies developed to capture environment fall studies in the community. The latter keywords, slightly varying for different databases, were environment design, environment, safety, home visits, home care services, occupational therapy, home accidents, hazards, modifications, housing for the elderly, patient discharge, home assessment, and home intervention.

Trials were included if they were randomized trials irrespective of whether or not treatment allocation was inadequately concealed, if they had a majority of people 65 years and older, and if the study population was living in the community, that is, not in a hostel, institution, or care home. The intervention had to be solely an environmental intervention but was not limited to any one professional group providing the intervention. Studies that included an environmental intervention as a component of a multifaceted intervention were not included.

Environmental interventions incorporate adaptations and modifications to the physical environment. This may also encompass changes in individual behaviors when negotiating and interacting with the environment and the management of the environment by organizational change and decision making. All studies irrespective of mode of delivery or who delivered the intervention were included.

**Data Extraction**

Three of the investigators independently screened the titles and abstracts of studies and assessed the eligibility of the studies for inclusion in the review. Data extraction was independently carried out by allocating two investigators to each trial and using a predetermined data extraction form, without blinding to authorship or journal. Four investigators conducted a reliability check in the first three trials comparing data extraction. Any discrepancies were resolved by discussion with other investigators. Additional information regarding the home hazard assessment and intervention and background information of study characteristics was sought from three original authors via e-mail.

**Outcomes and Comparisons**

The primary outcome of interest is the rate of falls or the proportion of fallers. Outcomes are expressed as relative risks (RR), which are incidence rate ratios for rates of falls or cumulative incidence ratios for proportions of fallers, with 95% confidence intervals (CIs). The outcome measure
depended on which measure was reported as the major outcome in published articles. Four trials reported incidence rate ratios (Campbell et al., 2005; Day et al., 2002; Nikolaus & Bach, 2003; Stevens, Holman, Bennett, & de Klerk, 2001) and two studies reported cumulative incidence ratios (Cumming et al., 1999; Pardessus et al., 2002). For meta-analyses, we used the random effects model, as it is a more conservative measure (Borenstein, Hedges, & Rothstein, 2007). It was decided a priori to analyze subgroups of studies according to baseline risk of falling and whether or not occupational therapists conducted the intervention. We were also interested in a broader range of potential comparisons but did not expect sufficient trials and/or information to permit meaningful analyses. These were injurious falls, age, gender, comorbidity, stroke, cognitive impairment or Parkinson’s disease, and adherence to recommendations.

Rating of Intervention

Interventions were rated according to the level of professional training of the interventionist and the intensity of the intervention. Professional training was considered at a high level when it involved an occupational therapist, ergotherapist or equivalent, as these professions have specific expertise evaluating both the person and the environment. Trial interventions were classified as high or not high intensity using four criteria based on best practice (Peterson & Clemson, 2008) and agreed on a priori by the investigators.

To be of high intensity, the intervention had to meet 75% (three fourths) of the agreed criteria. Criteria were (a) a comprehensive evaluation process of hazard identification and priority setting taking into account both personal risk and environmental audit, (b) the use of an assessment tool validated for the broad range of potential fall hazards, (c) inclusion of formal or observational evaluation of the functional capacity (physical capacity, behavior, functional vision, habits) of the person within the context of their environment, and (d) provision of adequate follow-up by the health professional and support for adaptations and modifications. Examples of interventions not considered high intensity include hazard identification only and a preset list and/or a limited list of hazards or solutions that may have omitted potentially important hazards. An additional fifth criterion, that the older person was actively involved in the audit and priority setting, was deleted as there was insufficient information.
Assessment of Methodological Quality

Trial quality was summarized overall for each trial based on eight criteria used in the Gillespie et al. (2005, p. 135) Cochrane review, with two additional items. These were the method of randomization generation to reduce selection bias based on Juni, Altman, and Egger (2001) and an item related to potential contamination bias, that is, if the environmental assessment was conducted with both the intervention group and controls. A criterion from the Gillespie et al. list not included in our trial quality list was the blinding of participants and interventionists to assignment, as it is not possible to blind participants who receive the home safety intervention.

Two key components were considered of prime importance when reporting the overall summary of trial quality. These were the method of randomization generation and the concealment of allocation sequences to investigators enrolling participants and to participants (Juni et al., 2001). Two additional items were also considered of high importance: intention to treat analysis and blinding of outcome assessors to treatment status.

Sensitivity and Statistical Analysis

Comprehensive meta-analysis software (Borenstein, 2006) was used to generate pooled estimates of effect sizes. Heterogeneity was assessed with the Q test and further validated with the $I^2$ formula for variability (Higgins, Thompson, Deeks, & Altman, 2003). For this latter statistic, the values of 25%, 50%, and 75% reflect low, moderate, and high variability. We explored the influence on effect estimates of excluding poorer quality studies and of excluding studies with extreme treatment effects. In addition, leave-one analysis was conducted to further explore variability. Leave-one analysis refers to systematically removing one study from the analysis at a time with the assumption that removing one of the studies from the meta-analysis should not affect the overall results. This occurring suggests heterogeneity among the studies.

Egger’s regression intercept of funnel plot asymmetry (Egger, Smith, Schneider, and Minder, 1997) was computed to test the presence of publication bias. Publication bias occurs most often when the results of negative trials are not published. Funnel plots graphically show the effect estimates compared to sample sizes of the published studies, with symmetry indicating an absence of publication bias. Egger’s regression intercept is a measure of asymmetry of the funnel plot, testing whether there is an effect
present because of the smaller studies that are likely to have less precision compared to bigger studies that tend to have more precision.

Results

Identifying Eligible Trials

We screened 388 abstracts and excluded 375 studies because 221 did not investigate the outcome of falls, 109 were not randomized controlled trials, and 45 did not focus on an aging population, were not community based, or did not offer a home environmental intervention (Figure 1). Overall, 12 studies were reviewed in detail. Of these, 6 trials (Campbell et al., 2005; Cumming et al., 1999; Day et al., 2002; Nikolaus & Bach, 2003; Pardessus et al., 2002; Stevens, Holman, Bennett, et al., 2001) (3,298 participants) were eligible for inclusion as they offered home environmental interventions as a single intervention.

Trial Characteristics

Table 1 describes the study characteristics. Countries of origin were Australia for three trials, Germany for one, France for one, and New Zealand for one. The mean age of participants at baseline was 79.6 years. The follow-up period was 12 months except for the period for Day et al. (2002), which was 18 months. Two studies (Campbell et al., 2005; Day et al., 2002) were factorial designs. In both of these only the single home visit intervention arm with comparison to the control arm was included in the analysis.

Methodological Quality of Trials

Trial quality is summarized in Table 1. All trials met at least 60% of the 10 criteria of trial quality at the highest level, with three meeting 100% (Campbell et al., 2005; Cumming et al., 1999; Nikolaus & Bach, 2003). Methods of allocation concealment were described in five of the six studies, with four of these either telephoning an independent person (Campbell et al., 2005; Cumming et al., 1999; Day et al., 2002) or using sealed envelopes (Nikolaus & Bach, 2003). Randomization was generated by a reported random sequence method in five of the trials, with the sixth (Stevens, Holman, Bennett, et al., 2001) using only stratification. A block design was reported in one (Cumming et al., 1999), and computer-generated random numbers were used in another (Campbell et al., 2005).
Figure 1
Flow Chart Identifying Studies

Potentially relevant publications identified and abstracts screened (n=388)

Excluded as research did not investigate an outcome of falls (n=221), or studies were not RCTs (n=109)

Full paper screened (n=58)

Excluded because:
- Not related to an aging population (n=3)
- Not community based (n=21)
- No home environmental interventions (n=21)

Potentially eligible trials (n=12)

Excluded as home environmental intervention was part of multi-faceted intervention (n=6)

Trials included in the meta-analysis (n=6)

Note: RCT = randomized controlled trial.
Table 1
Trial Characteristics

<table>
<thead>
<tr>
<th>Study</th>
<th>Source of Population</th>
<th>Age at baseline ((M, SD)), % Female, Fall Status at Entry</th>
<th>No. of Participants ((\text{Intervention/Control}))</th>
<th>Randomization</th>
<th>Concealment Allocation</th>
<th>Composite Score ((\text{Out of 10})^b)</th>
<th>Specialization of Provider</th>
<th>Meets Three Fourths of Criteria at Highest Intensity</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumming et al. (1999)</td>
<td>Majority recruited as inpatients in hospital. Others were from a local day center ((n = 80)) and outpatients ((n = 25)); &gt; 65 years</td>
<td>76.4, 7.1; 57% female; 39% had fallen one or more times in past year, 17% two or more times</td>
<td>264/266, 103/103c</td>
<td>A</td>
<td>A</td>
<td>10</td>
<td>Occupational therapist</td>
<td>Yes</td>
<td>1 to 2 visits postdischarge using comprehensive and validated tool (Clemson, Fitzgerald, &amp; Heard, 1999) with protocol based on the Westmead approach (Clemson, 1997). Recommendations included hazard reduction, behavioral changes, and footwear. Follow-up support.</td>
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<td>Study</td>
<td>Source of Population</td>
<td>Age at baseline ((M, SD)), % Female, Fall Status at Entry</td>
<td>No. of Participants (Intervention/Control)</td>
<td>Trial Quality</td>
<td>Intervention Intensity</td>
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<td>Stevens, Holman, Bennett, and de Klerk (2001)</td>
<td>State electoral roll plus older people cohabitating with index recruits, &gt; 70 years</td>
<td>76, 53% female, 27% had fallen in past year</td>
<td>635/1,244</td>
<td>B B 7 (randomization generation; concealment; blinding of outcome assessors)</td>
<td>Research nurse Ergotherapist</td>
<td>No</td>
<td>Preset list of 11 hazards, advice provided to remediate three of these, educational pamphlet provided (Stevens, Holman, &amp; Bennett, 2001).</td>
<td></td>
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<td>Pardessus et al. (2002)</td>
<td>Hospitalized for falling; in patient of acute medicine department, &gt; 65 years</td>
<td>83.5, 7.7; 78% female; 100% were fallers in the past year</td>
<td>30/30</td>
<td>A B 6 (Concealment; Blinded outcome assessors; Fall outcome not defined; Interval recall of falls after 6 months)</td>
<td>Trained assessor Assessment tool not described</td>
<td>Yes</td>
<td>Predischarge home visit with follow-up visit. Aim to decrease falls and increase autonomy. 2-hr visits to evaluate abilities in real-life environment, included ADL/ IADLs, transfers, and mobility. Modifications and hazards removed plus advise on safety.</td>
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<tr>
<th>Study</th>
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<th>No. of Participants (Intervention/Control)</th>
<th>Trial Quality</th>
<th>Intervention Intensity</th>
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<tbody>
<tr>
<td>Day et al. (2002)</td>
<td>Australian electoral role, 70 years and older, living in own home, allowed to make home modifications; general practitioner approval</td>
<td>76.1, 5.0; 60% female; 6% had a history of falls in past year</td>
<td>136/137</td>
<td>A A 8 (comparability of groups at baseline; potential bias as hazard assessment conducted with both intervention and control)</td>
<td>Trained assessor No Structured assessment checklist of physical attributes of environment; however, had minimal fall hazard descriptors; informed by letter of proposed interventions.</td>
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<td>Nikolaus and Bach (2003)</td>
<td>Inpatient of geriatric clinic, multiple chronic conditions or functional deterioration and could be discharged home, previous fall</td>
<td>81.5, 6.4; 73% female; 70% had one fall; 30% had two or more falls in past year</td>
<td>181/179, 53/55c</td>
<td>A A 10</td>
<td>Occupational therapist accompanied by physical therapist or nurse according to anticipated need and functional limitations Yes Two home visits (M = 2.6), used standardized home safety assessment (Nikolaus et al., 1995). Second visit to discuss fall risks in the home and facilitate changes and home modifications.</td>
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<td>Campbell et al. (2005)</td>
<td>Vision 6/24 or worse in better eye with best correction; blind registry, low vision clinics and ophthalmology practices; &gt; 75 years, living in community</td>
<td>83.5, 4.7; 68% female; 47% history of falls in past year</td>
<td>100/96</td>
<td>A</td>
<td>A</td>
</tr>
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</table>

Note: ADL = activity of daily living; IADL = instrumental activity of daily living.
a. A = adequate; B = unclear or potential selection bias.
b. Categories not meeting trial quality or not reported.
c. High-risk subgroups (Cumming et al., history of falls in past year; Nikolaus and Bach, history of two or more falls).
Effect on Fall Reduction

The analysis is based on the six trials and includes the total number of people (3,298; see Figure 2). The reduction in risk was modest but significant, with a 21% reduction in falls (RR = 0.79, 95% CI = 0.65 to 0.97). Significant heterogeneity (p < .01) was present, and explanations were explored as part of the sensitivity analysis.

Effect on Fall Reduction for At-Risk Older People

Four trials provided data on fall reduction for a total of 570 high-risk people, that is, those with known risk factors for falls at baseline (Figure 3). These included a history of falling or multiple falls in the past year, hospitalization for a fall, functional decline, or severe vision impairment. The Cumming et al. (1999) study provided a subgroup of people with a history of falling (n = 206). The Nikolaus and Bach (2003) study also provided a higher-risk subgroup of multiple fallers in the past year (n = 108).

The reduction in risk was important and clinically significant, with a 39% reduction of falls (RR = 0.61, 95% CI = 0.47 to 0.79). Analysis of heterogeneity found that these four trials were homogeneous (p = .16). They produced an absolute risk difference of 26%, for a number needed to treat of four people.
Data were not available to report risk differences for the full six trials, but it was possible to explore comparisons for individual trials. The Nikolaus and Bach (2003) trial with a larger sample ($n = 360$) had a risk difference of 6%, for a number needed to treat of 17 people, whereas their higher at-risk group ($n = 108$) had a risk difference of 25%, for a number needed to treat of just 4 people. For the Cumming et al. (1999) study, the number needed to treat was calculated as 12 for the larger sample ($n = 530$) and 4 for the high-risk group ($n = 206$).

**Sensitivity Analysis**

Because of the significant heterogeneity present across the six trials (Figure 2), we conducted further meta-analyses to explore the influences on effect estimates. Removing the studies of lesser scientific rigor, based on the criteria for randomization method and allocation concealment, did not eliminate heterogeneity (data not shown). However, removing the Campbell et al. (2005) study, which was the study with the largest effect size, did result in a homogenous group with a nonsignificant $Q$ value of 5.01 ($df = 4$, $p = .29$; $I^2 = 20$, low variability). The population in the Campbell et al. study was people with significant visual deficits, a particularly high-risk and vulnerable group.
Leave-one analysis showed that findings were not unduly influenced by any single study, giving support to the belief that the major outcome of the six trials, despite the heterogeneity, is acceptable. Heterogeneity was not present in a substudy of four trials (Figure 3), even though it included the Campbell et al. (2005) study.

Four trials (Campbell et al., 2005; Cumming et al., 1999; Nikolaus & Bach, 2003; Pardessus et al., 2002) had high-intensity interventions, and these were also the trials in which the interventions were conducted by occupational therapists (see Table 1). The high-intensity interventions ($n = 4$) were highly effective ($RR = 0.68$, $95\%$ CI $= 0.50$ to $0.91$), and the non-high-intense interventions ($n = 2$) were not effective ($RR = 0.96$, $95\%$ CI $= 0.84$ to $1.09$).

**Publication and Small-Sample Bias**

Egger’s regression test provided no evidence of small sample bias. The size of estimate did not appear to vary with sample size, implying our results are not influenced by publication bias. Funnel plot results are available from the first author.

**Discussion**

This systematic review and meta-analysis showed that delivering home environmental interventions is effective for falls prevention. Our results demonstrate that the risk of falls was reduced by 21% across all studies and 39% among populations at high risk for falls. High-risk groups were people who had had a history of falling in the past year, who had been hospitalized for a fall, who showed functional decline, and who had severe visual impairment. This study strengthens and compliments the Cochrane findings (Gillespie et al., 2005) particularly because it establishes criteria for examining the intensity of interventions, thus discerning difference, and provides sensitivity analysis to help explain effect sizes.

The outcomes of this study generate policy, practice, and resource allocation implications with a pragmatic recommendation that environmental interventions undertaken by appropriately trained individuals should be offered to at-risk populations. Although the results did show statistically significant benefits for unselected populations, it is acknowledged that resources are best allocated where they can make the most difference. The findings indicate that targeting higher-risk people greatly reduces the
number needed to treat for a clinically effective risk-reduction outcome. The reduction of risk of a falls-prevention intervention that can be provided by just one or two home visits is potentially cost-effective and desirable. Campbell et al. (2005) reported the incremental cost per fall prevented as NZ$655, and Salkeld et al. (2000) reported the cost as Aus$119 per fall prevented for people with a history of falls.

Subanalyses were limited because of the lack of consistent reporting of measures across trials. There was limited reporting of injurious falls, fractures, effects of safety advice on activity levels, self-efficacy, and the adoption of protective behaviors. Two studies explored functional status and autonomy levels with positive outcomes (Nikolaus & Bach, 2003; Pardessus et al., 2002), which was also a focus of their specific predischarge interventions.

The limitations of this study relate to the small number of published studies. Many other studies include environmental modification as a component within a multifaceted approach; however, it was not possible to extract specific outcome performance from these studies. Several trials have evaluated dual interventions. In Campbell et al.’s (2005) 2 × 2 factorial study, the occupational therapy home assessment and intervention was effective in reducing falls in people with severe visual impairment, whereas exercise alone did not reduce falls. The combination of exercise and home assessment did reduce falls but to a lesser extent than home safety alone. By contrast, Day et al. (2002) did show a benefit when interventions were “added on” in their factorially designed study that targeted the general population of older people. Evidence available to date suggests that interventions to prevent falls need to be population specific and that a one-size-fits-all approach will fail to deliver significant population-level falls and fracture reduction. We support further research to investigate the efficacy of specific groups of dual interventions that are well planned and integrated to enhance the opportunity for increasing benefit.

Results support the view that the intensity of the intervention can make a difference. How the assessment and evaluation are conducted, what is offered, and adequate follow-up all combine to produce positive results. We support the Cochrane assertion (Gillespie et al., 2005) that a health professional who is trained to evaluate the person and the environment should be designing and conducting such interventions.

We proposed a definition of what a high-quality intervention should be, providing a standard for researchers and developers of practice guidelines. The review identified circumstances under which hazard reduction is effective. On the surface it appears simple, but in fact it is more complex than just...
identifying specific hazards for change. A comprehensive assessment involves the full range of potential hazards (Clemson, Fitzgerald, & Heard, 1999; Nikolaus et al., 1995), raising the awareness of older people about their environment, how they negotiate it, and problem-solving solutions (Clemson, Cusick, & Fozzard, 1999). Occupational therapists make judgments as to what is an environmental hazard based on the relationship between the person and the environment. Such judgments are based on considering a range of factors. These include history of falls, patterns of usage of the home, protective and risk-taking behaviors, functional vision, physical and cognitive attributes that affect mobility and task performance, and fall risk in specific situations such as reaching, climbing, and transferring (Clemson, 1997; Peterson & Clemson, 2008). Case-control, cohort, and qualitative studies (Clemson, Manor, & Fitzgerald, 2003; Lord et al., 2006; Northbridge, Nevitt, & Kelsey, 1996) have suggested that hazards are riskier for people with balance and other conditions related to frailty and that behavior change strategies need to be employed. Adherence to behavioral change recommendations was shown to be very good (60%) in a follow-up study to the Cumming et al. (2001) trial.

We recommend using existing validated assessment tools to assist in priority setting and to evaluate the person and his or her fall history, and we note that follow-up and support for recommendations are vital. Seldom have fall intervention studies directly addressed strategies for safely negotiating community and public places, with few exceptions (Clemson et al., 2004). Research is also needed to determine whether environmental fall strategies can be adapted for people with Parkinson’s disease, stroke, or cognitive impairment, three high-risk groups that we know experience a much higher incidence of falls.

Aging in place (Kendig & Duckett, 2001), the cornerstone of current policy on aging, gives credibility to the focus on fall management and safety at home. General practitioners are relied on to manage the needs of older patients who are falling. They need to know to whom to refer their patients and what standard of care they should expect from community services. This review suggests that environmental interventions should be part of predischarge planning for those at highest risk and postdischarge follow-up for those with a history of falls. More than 11% of people 85 and older each year end up in an emergency department (NICE, 2004), and we suggest that older people admitted to orthopedic and emergency departments following a fall should be included in this high-risk group. Evidence already exists to support a multifaceted approach in fallers presenting to the emergency department, which includes home assessment and intervention undertaken by an occupational therapist (Close et al., 1999).
There is now evidence that home visit interventions that are comprehensive, are well focused, and incorporate an environmental-fit perspective can be successful in reducing falls with clinically significant effects when targeted to specific high-risk groups. It makes sense that a compensatory technique such as increasing awareness, increasing safety practices, and reducing hazards in and about the home environment for older people who are at risk would work.

References


